NASA CR-54926
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Summary Report

ATMOSPHERIC DIFFUSION OF FLUORINE FROM SPILLS OF FLUORINE-OXYGEN MIXTURES

Prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Contract NAS 3-3245

GENERAL DYNAMICS
Convair Division

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May 10, 1966

CONTRACT NAS 3-3245

Technical Management
NASA Lewis Research Center
Cleveland, Ohio
FLOX Project Office

GENERAL DYNAMICS
Convair Division

FOREWORD

This is the final report on Contract NAS3-3245, Task Orders 2 and 6, covering the period from March 5, 1965, through January 31, 1966. The work performed under the contract was administered by the FLOX Project Office of the NASA Lewis Research Center under the direction of Mr. Howard Douglass. Mr. Harold Schmidt of the same office was technical contract monitor.

The report is in two parts. Part 1 covers the work performed by General Dynamics Convair; Part 2 covers the work performed by Meteorology Research, Inc., under subcontract to Convair. Mr. J. R. Thayer, Convair program manager, and Mr. J. H. Hood were the principal contributors to Part 1. Dr. T. B. Smith was the program manager for work performed by Meteorology Research, Inc.

All motion picture test film footage and a 20-minute, 16-mm silent color film documentary of test operations were submitted to Lewis Research Center to supplement this report.

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ABSTRACT

Atmospheric diffusion tests were conducted to determine the plume trajectory and downwind boundary dosages for noncombustive and combustive fluorine spills under a variety of atmospheric conditions. The trajectory of a hot conflagration cloud resulting from spills of up to 3000 lb of a 30 percent LF_2/70 percent LO_2 mixture on fuel was determined by photographic recording and IBM 7094 computation. Two fluorine and two hydrogen fluoride atmospheric samplers in the sensitivity range of 1 to 500 ppm-min by volume were evaluated in field trials. The evaporation rate of liquid LF_2/LO_2 mixture from a simulated spill containment system was determined, and the blast overpressure associated with a LF_2/LO_2 reaction with RP-1 fuel was measured. The capability of Sycamore Test Site for fluorine testing was determined.

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PART 1

I SUMMARY

This is the final report of a fluorine diffusion program conducted by Convair division of General Dynamics at Sycamore Test Site, San Diego, California for the National Aeronautics and Space Administration, Lewis Research Center, under contract NAS3-3245.

This program was conducted to determine the feasibility and attendant limitations of conducting space vehicle system tests using an oxidizer containing fluorine. These future tests would include infrequent but large-scale releases of fluorine and hydrogen fluoride into the atmosphere. The present program was to demonstrate the diffusion characteristics of spills of fluorine-oxygen mixtures, and to define the pertinent characteristics of fluorine relative to the release and dilution in the atmosphere. Field instruments for the measurement of part per million concentrations of fluorine and hydrogen fluoride in the air also were developed and tested. The overpressure characteristics of fuel-fluorine oxygen spill were also determined.

The test period began in May 1965 and extended through September 1965, and was preceded by one year of recording climatalogical parameters in the Sycamore area. Soil and water samples also were obtained before and after the tests to evaluate the pollution load on the surface of the downwind sector.

Tests were of three categories:

1. Natural diffusion experiments with fluorescent tracer particles (FP) to establish diffusion characteristics and locate plume trajectory.

2. Non-combustive spill tests with LOX and a 30 percent LF_2/70 percent LO_2 mixture to determine evaporation rate, evaluate water fog as a suppression technique, and obtain field measurements of F_2 and HF. Diffusion trials were also conducted during these tests to reveal if the cryogenic plume had any effect on tracer diffusion.

3. Combustive spills of 30 percent LF_2/70 percent LO_2 on either RP-1 or charcoal fuel to determine the diffusion characteristics of a conflagration release. During this series of experiments the cloud trajectory was measured photographically to determine the potential for inversion penetration. F_2 and HF surface concentrations were measured, diffusion experiments were conducted to find the trajectory surface location and distribution, initial cloud temperature was measured to aid in buoyancy analyses, and overpressure was measured to determine the blast characteristic of the fuel/oxidizer reaction.

Diffusion data obtained in work done by Air Force Cambridge Research Laboratories was useful in these tests. The Cambridge-developed WIND

(Weather Information Network and Display) equation (Reference 1) was used as a baseline to determine the order of variation between the diffusion effectiveness of the Sycamore Test Site and the relatively flat terrain where WIND diffusion tests were performed.

A. Conclusions

1. Containment of a non-combustive spill of 30 percent LF_2/70 percent LO_2 in a concrete sump to reduce source strength is feasible. Such a system has the additional advantage of allowing time for additional suppression or neutralization with minimum facility damage.

2. Hydrolysis of fluorine to less toxic hydrogen fluoride occurs in the atmosphere. The rate of hydrolysis is very high initially, but decreases rapidly as the fluorine diffuses.

3. Penetration of most inversions with the hot products of a full-scale Atlas conflagration of fuel and oxidizer is probable. This will significantly reduce the downwind dosages.

4. There is no overpressure accompanying the open-spill reaction of RP-1 and 30 percent LF_2/70 percent LO_2 in the atmosphere.

5. Water fog sprayed over and onto the sump containing 30 percent LF_2/70 percent LO_2 greatly increased boil off rate, but the tests indicated a significant amount of the F_2 was scrubbed from the boil off gases. A fog system might be made more effective by arranging fog patterns to scrub the evolved vapor and convert it to an aqueous solution of HF at the source.

6. Spills of 30 percent FLOX onto charcoal, spread over a flat unconfined surface as tested, resulted in a very smooth burning reaction, with combustion efficiency up to 40 percent. A spill configuration that would provide higher combustion efficiency would be desirable, for a more effective use of this reaction for pollution control, by the conversion of fluorine to non-toxic CF_4.

7. The use of smoke to make the cloud trajectories more visible was advantageous in this program.

8. All of the test fixtures (tanks, tank supports, transfer and vent lines, instrumentation conduit) survived the eleven hot spill tests with virtually no damage. This equipment is representative of hardware on a static test or launch site, and demonstrates the survivability of facilities after repeated exposure to FLOX fires of short duration but high temperature. This characteristic is attributable to the absence of overpressure and the rapidity of the reaction.

9. Part per million concentrations of fluorine and hydrogen fluoride can be measured reliably in the field. These measurements were quantitatively validated by using a fluorescent tracer material. Qualitative validation was accomplished by using photographic tracking techniques.

10. The measured deviation between calculated and observed doses of tracer particles, fluorine, and HF are nearly identical (Figure 4-12) and suggest that no improvement in diffusion prediction would be made by using a diffusion model for Sycamore Test Site more appropriate to an instantaneous source.

11. A major factor in the above conclusion was the frequent existence of an inversion about 500 feet above the ridge that limited upward travel of the hot cloud.

12. Comparative results of the hot and cold source diffusion pertain only to Sycamore Test Site where local terrain caused the cold cloud to take an elevated configuration as it moved downwind.

13. Based on current allowable dose criteria at the Sycamore Test Site boundary and the results of the test program, test operations involving Atlas- or Centaur-size vehicles with a significant quantity of fluorine oxidizer are feasible.

14. The climatalogy of the Sycamore Test Site assures a high percentage of operable conditions. The requirements of a wind from the western quadrant, an inversion above 1500 ft, and solar heating of the slopes are met 50 to 70 percent of the year between 10:00 a.m. and 4:00 p.m.

15. The pollutional load on the natural drainage area to the east of Sycamore Test Site is insignificant.

B. Recommendations

1. Compartmentation and spill containment should be designed into any fluorine or FLOX storage and transfer system. Optimum design of the compartment should be based on the maximum-volume to wetted-surface-area ratio attainable using conventional construction shapes.

2. Additional work should be done to define the process of hydrolysis in the atmosphere as a function of time, temperature, concentration, turbulence, and humidity.

3. The fluorine electrochemical indicator-recorder and the F_2, HF dosimeter should be used to meet any future need for a fluorine monitor.

4. A hydrogen fluoride indicator-recorder should be developed to complement the electrochemical fluorine instrument and the chemical dosimeter.

5. The RP-1 reaction with FLOX or fluorine should be classified as hypergolic and non-explosive in any exclusion distance criteria.

6. Sycamore Test Site should be considered a suitable location for fluorine testing with the upper limit of fluorine in a credible release mode set at about 6,000 lb of F_2 or 30,000 lb of HF.

7. Fluorine testing at Sycamore should be under the operational control of a meteorologist with sufficient data at his disposal to predict downwind dosages.

8. The downwind boundary of Sycamore Test Site should be fenced and patrolled to exclude non-operating personnel from the area during fluorine testing.

9. The 2-mile unoccupied area to the east of the test site boundary should be established as a buffer zone during fluorine testing.

10. The test site should be re-evaluated prior to a future commitment to a fluorine test program since the development of the area to the east of Sycamore Test Site will increase with time.

II. INTRODUCTION

A. Background

During 1963, it became apparent that certain mission/payload requirements could be met by adding liquid fluorine (LF_2) to the liquid oxygen (LO_2) oxidizer in the Atlas SLV-3. This mixture, designated by the acronym "FLOX," is described by the percent by weight of fluorine; i.e., 30 percent FLOX is 30 percent by weight LF_2 and 70 percent by weight LO_2. In this report, mixtures are designated as percent LF_2/percent LO_2.

The addition of LF_2 increases the performance capability of the vehicle in two ways: first through the increase in specific impulse of RP-1 fuel, and second through the higher LF_2 density, which permits more oxidizer weight to be loaded into given-sized tanks to increase the burn time and total impulse. These performance improvements are effective up to a mixture of 70 percent LF_2/30 percent LO_2 with RP-1 fuel.

The use of FLOX required study of three areas:

1. Oxidizer system material compatibility with fluorine.
2. Combustion phenomena in the thrust chamber.
3. Operational hazards related to the introduction of toxic F_2 to oxygen and the RP-1/F_2 combustion product, HF (also toxic although less so than elemental fluorine).

Compatibility of the oxidizer system with fluorine was extensively investigated by NASA LeRC and Convair in a series of studies of materials, cleaning and passivation techniques, and flow tests. This work was developed to full-scale compatibility tests of critical Atlas oxidizer components, including the tank, under simulated operational conditions. Convair performed this work during 1964 under contract to NASA LeRC. All tests were completed satisfactorily and demonstrated the practicality of using existing components with up to 30 percent LF_2/70 percent LO_2. Minor changes in soft sealing material were indicated, and minor design changes were considered necessary to ensure thorough cleaning and passivation of inaccessible areas. This work is reported in Reference 2.

A follow-on program was initiated during 1965 to subject the boiloff valve assembly to a simulated life cycle and vibration test with 50 percent LF_2/50 percent LO_2. This work was satisfactory completed in December 1965.

During 1963-1965, the Rocketdyne Division of North American Aviation performed tests on Atlas vernier and sustainer engines and oxidizer feed system components with various LF_2/LO_2 mixtures up to approximately 70 percent LF_2. These tests verified the theoretical specific impulse improvement and confirmed the compatibility of the system, again with minor changes indicated in soft seals and component design to facilitate thorough cleaning and passivation.

The success of these programs established the feasibility of substantial uprating of the launch vehicle at relatively low development costs.

B. Fluorine Toxic Hazards

Existing static test facilities and launch sites may be modified for fluorine use by the addition of a fluorine mix, storage, and transfer system, a purge and vent system, and a fluorine disposal system. However, due to the toxicity of fluorine, the site must be suitably isolated from other facilities and from populated areas to preclude personnel injury or property damage.

Although toxic propellants in massive quantities are in operational use (e.g., nitrogen tetroxide, UDMH, solid grain constituents, RFNA), fluorine use in flight-type equipment has been confined to relatively small quantities. The evaluation of fluorine hazards relative to such static test and launch site events as propellant transfer, tanking, and firing and such catastrophic events as massive spills, destruct, or fallback requires fundamental data specific to fluorine. These data requirements include: threshold limit concentrations for inhalation; evaporation rates; rate of conversion of fluorine to hydrogen fluoride by hydrolysis; the dynamics of a hot cloud rise from a conflagration; and the diffusion of pollutants from this hot cloud to surface level.

Extensive studies and experimental work preceded the introduction of nitrogen tetroxide to the Air Force Eastern Test Range (ETR) and Western Test Range (WTR). The prediction of toxic vapor concentration downwind from non-combustive spills by the WIND system is a significant product of this work and is directly usable with fluorine once the evaporation rate is known. Studies of fluorine in the amount required for 30 percent FLOX in the Atlas SLV-3 revealed that the toxic hazard at either ETR or WTR was less than the hazard from N_2O_4 accompanying the launch of a Titan II or III vehicle. The immediate problem, therefore, was to establish the suitability of a static test facility in which to perform tests and operations in support of the vehicle systems development, and to determine the handling characteristics of fluorine to permit more precise application of the WIND system. Since the Sycamore Test Site had been used in the Atlas development program and all facilities were on a standby status, it was logical to plan its use for fluorine development.

Site S-3 within the Sycamore Test Site complex was designated for possible use as the static facility. Accordingly, this program was designed to be conducted at S-2.

C. Objectives

The fundamental objective of this program was to experimentally investigate the most important factors that influence the diffusion of fluorine and hydrogen fluoride in the atmosphere. The source of these materials in a launch vehicle development and operational program would be accidental and intentional releases. The factors investigated were:

1. Diffusion of fluorine and hydrogen fluoride into the atmosphere resulting from non-combustive and combustive spills and engine firing.

2. Methods of spill control including inerting reactions with charcoal, water suppression, and containment.

3. Measurement of overpressure from FLOX-RP-1 reactions.

4. Deposition of fluorides on the ground surface of the downwind drainage area.

5. Hydrolysis of fluorine to hydrogen fluoride with atmospheric moisture.

6. Measurement of part per million concentrations of fluorine and hydrogen fluoride in the atmosphere near the surface out to 5 miles from the release point.

7. Quantitative limits for fluorine system testing at the Sycamore Test Site based on analyses of the above experimental data.

III TEST FACILITY

A. Sycamore Test Site

1. General

Sycamore Canyon is 16 miles northeast of San Diego, California. The test site is on 7600 acres of NASA property within the boundaries of the Camp Elliott Naval Reservation. The site was chosen to provide facilities for the static test firing of Atlas missiles. The Convair Test Center is located on 2400 acres of General Dynamics property bordering the NASA property on the North. (See Figure 3-10.)

The individual test sites are established on terrain composed of steep hills and valleys, providing excellent isolation for test stands and support facilities. There is a minimum noise problem to surrounding communities, and water and power supplies are adequate for present needs and future expansion.

The first static firing of an Atlas missile was made at the Sycamore Test Site on Stand S-1 in 1956; Test Stand S-2 was activated in 1958. A Centaur stand, S-4, was activated in 1960. Many Atlas missiles and Centaur space vehicles have been hot-fired to maximum run durations, and a variety of dynamic tests have been performed at the site.

2. S-4 Complex

The S-4 test stand and associated facilities are devoted to testing the Centaur vehicle, and incorporate many of the facilities formerly in the Atlas S-1 complex. This site is a likely site for a high energy upper stage or kick stage static test program.

The vertical, 66-ft, open-steel-framework stand accommodates the complete upper-stage Centaur vehicle. The vehicle is mounted within the test stand on a captive firing adapter. A liquid hydrogen storage facility is located about 150 ft from the stand at a lower elevation, which provides blast protection. Fuel from the 28,000-gallon LOX tank is transferred to the vehicle through a 3-1/2-inch, vacuum-jacketed line by pressurizing the storage tank. The LOX tank is about 675 ft from the stand, and transfer is accomplished remotely through an insulated transfer line.

Coolant water is provided for the diffuser and flame deflector in adequate quantities, and there are three primary Firex systems to protect the tower structure. A 5,000-gallon LN_2 storage tank supports the operations of this stand.

The Centaur test facility has a landline instrumentation system with a capacity for continuously recording 236 channels of data during a test run. Seven closed-circuit television systems are available. Telemetry trailers are used, and there is a multichannel intercommuncation system connecting the blockhouse, test stand, fuel and oxidizer storage areas, observation stations, administration building, and telemetry ground station trailer.

The blockhouse, 630 ft from the test stand, is equipped with complete instrumentation and remote control facilities and has explosion-proof windows and periscope observation facilities.

The complex is equipped with a steam ejector system that can create an extremely low-pressure environment around the main engines, thereby simulating the conditions that would be encountered in upper-stage engine starting.

Since both S-2 and S-4 complexes are about equidistant from the boundary and are similarly situated from the standpoint of terrain and climatology, it is felt that the results of this program apply equally well to both sites, although the work was accomplished at S-2.

3. S-2 Complex

The S-2 test stand was originally designed for Atlas missile static test firing, but is readily convertible for similar applications. Supporting facilities include a two-story concrete blockhouse, liquid oxygen storage, gaseous nitrogen cascade and distribution system, helium distribution, power substation, utility building, water distribution, carbon dioxide storage, compressed air, full camera coverage, and an extensive fire protection system. There is an instrumentation system that can accommodate over 600 channels of test data and a very flexible communication system.

The stand can be modified for testing vehicles with engines of more than 1-million pounds thrust. The modifications will depend upon the vehicle to be accommodated, the type of propellants and quantity, the engine characteristics, and the need for diffusers and ejectors. Modifications would represent a very moderate cost compared with the investment required to establish another complex.

B. Modification of S-2 Test Facility

The test facility for this program was designed as an extension of an existing fluorine storage, loading, and transfer facility at S-2. The existing fluorine facility (Figure 4-1) was designed and built in 1963 under Contract NAS3-3228, Task Order 9. The facility is described in Reference 2.

A triple-wall tank is used for mixing and storing LF_2 and LO_2. The inner tank is a 450-gal product tank surrounded by the LN_2 jacket and an outer vacuum chamber. Transfer is accomplished by helium pressurization of the product tank. Liquid quantity is measured by a helium bubbler with remote digital readout and recording of differential pressure. Helium is also used for system purging to prevent condensation of moisture. A dew point of -150°F is maintained by a helium drying system. The system is vented by discharge through a charcoal burner.

The spill test pad was located approximately 300 ft south of the storage tank to place the fluorine release point adjacent to the exhaust of the S-2 static test facility, yet far enough away to prevent damage from the fireball or debris. A transfer line to the test pad was connected to the existing fluorine facility through a cross in the outflow line from the storage tank. This connection and the associated controls were the only facility modifications required for these tests.

C. Design and Construction of Spill Test Facility

The spill test facility was designed as an extension of the existing S-2 complex for FLOX loading, transfer and storage with new facilities added for the spill test area. An overall view of the S-2 test area is shown in Figure 3-2.

Major items of equipment added for atmospheric diffusion testing are described in succeeding paragraphs.

1. Spill Test Pad. (See Figure 3-3.) A 30 × 30 ft concrete pad enclosing four spill basins was designed and constructed for use as the spill test site. The basins were sized to obtain different evaporation rates.

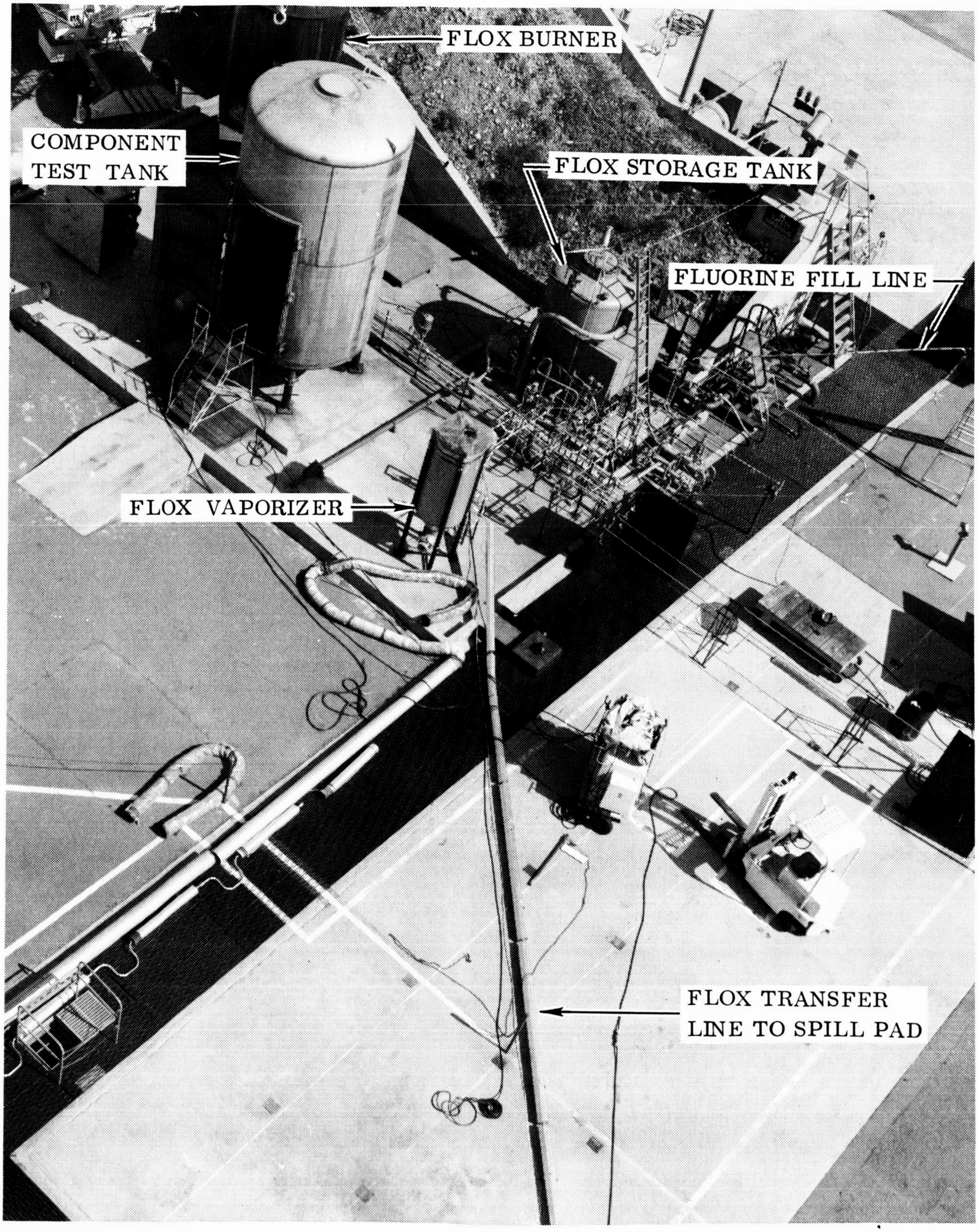


Figure 3-1. FLOX Storage, Loading, and Transfer Facility at S-2

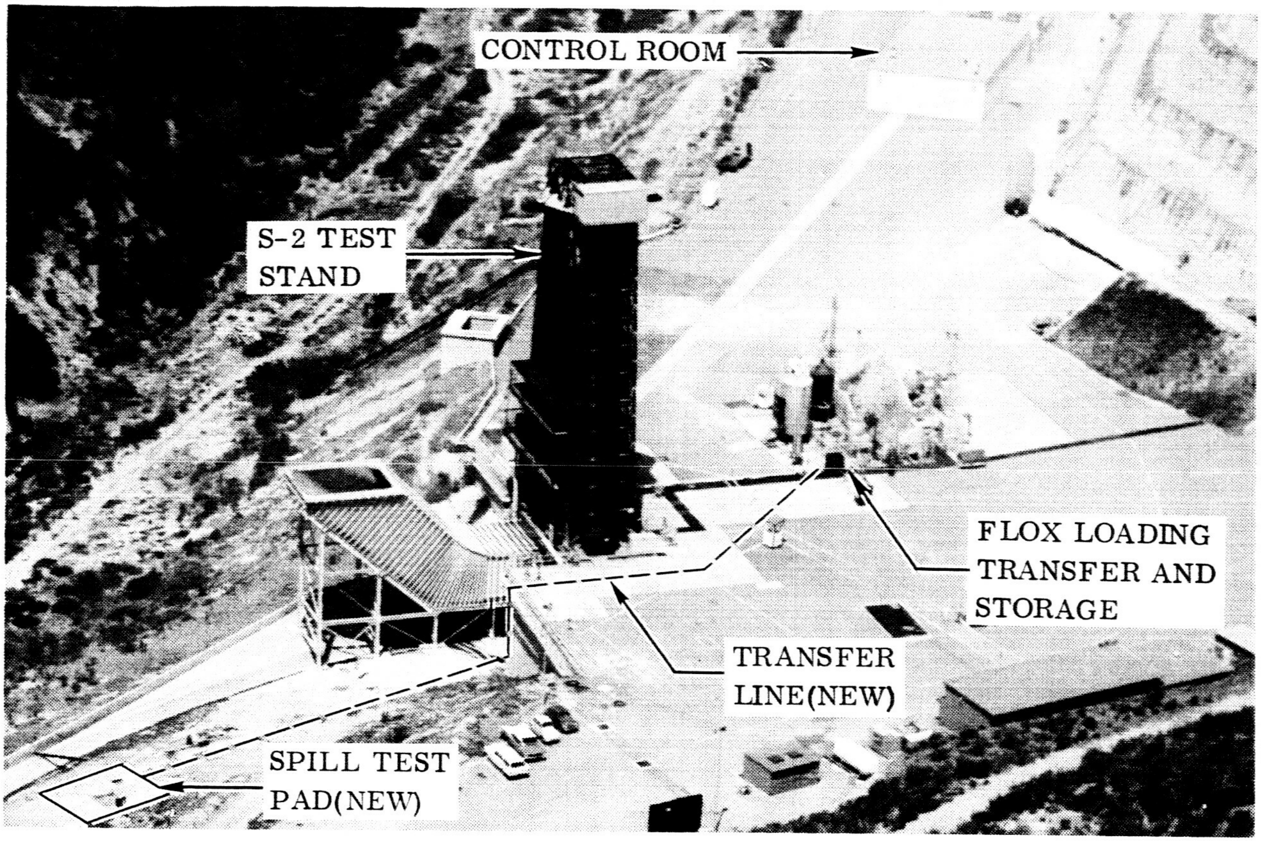


Figure 3-2. S-2 Complex as Modified for FLOX Spill Tests

2. FLOX Transfer System. (See Figure 3-4.) The FLOX transfer line (1 × 0.028 CRES with 45-deg flared fittings and soft copper seals) was attached to the existing facility downstream of the FLOX vaporizer. An existing LOX dump trench was used to route the transfer line to the test site. Motion limit anchors were used to secure the line, which was insulated with 2-1/2 inches of polyurethane foam to minimize line boil-off losses; tube fittings were not insulated.

A pneumatically-controlled Annin valve with a copper seat and a CRES plug was used to control flow through the transfer line. The valve was positioned behind a blast shield at the edge of the spill test pad. A 1-inch line connected the valve to the evaporation pit or spill tank.

3. Water Deluge and Fog System. The water deluge and fog system was designed around an existing water manifold obtained from S-1. Only minor modification was necessary to adapt the unit for S-2 testing. Water was supplied to the system through firehoses from an existing fireplug and manifold. Supply pressure at the manifold was approximately 150 psig.

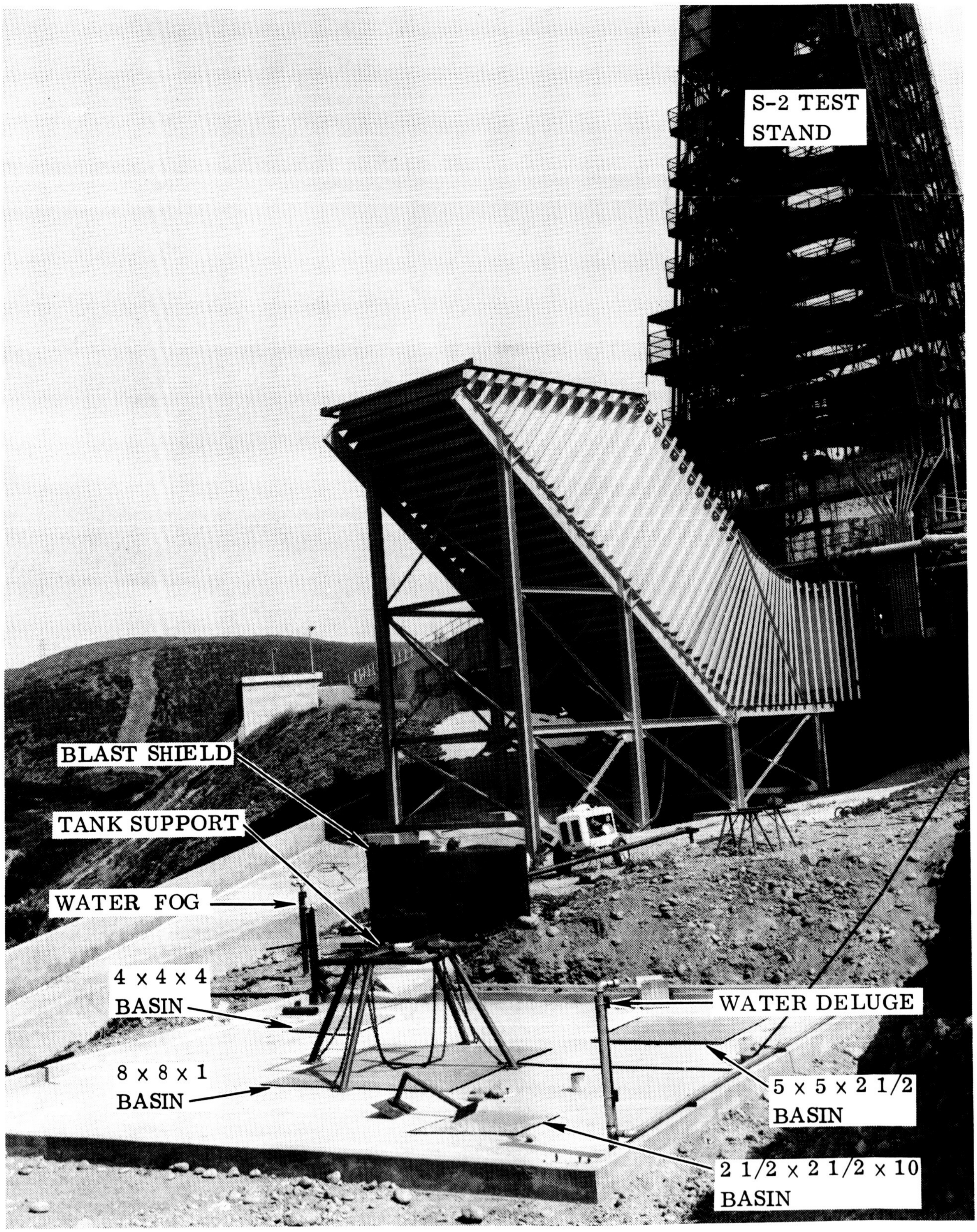


Figure 3-3. FLOX Spill Test Pad

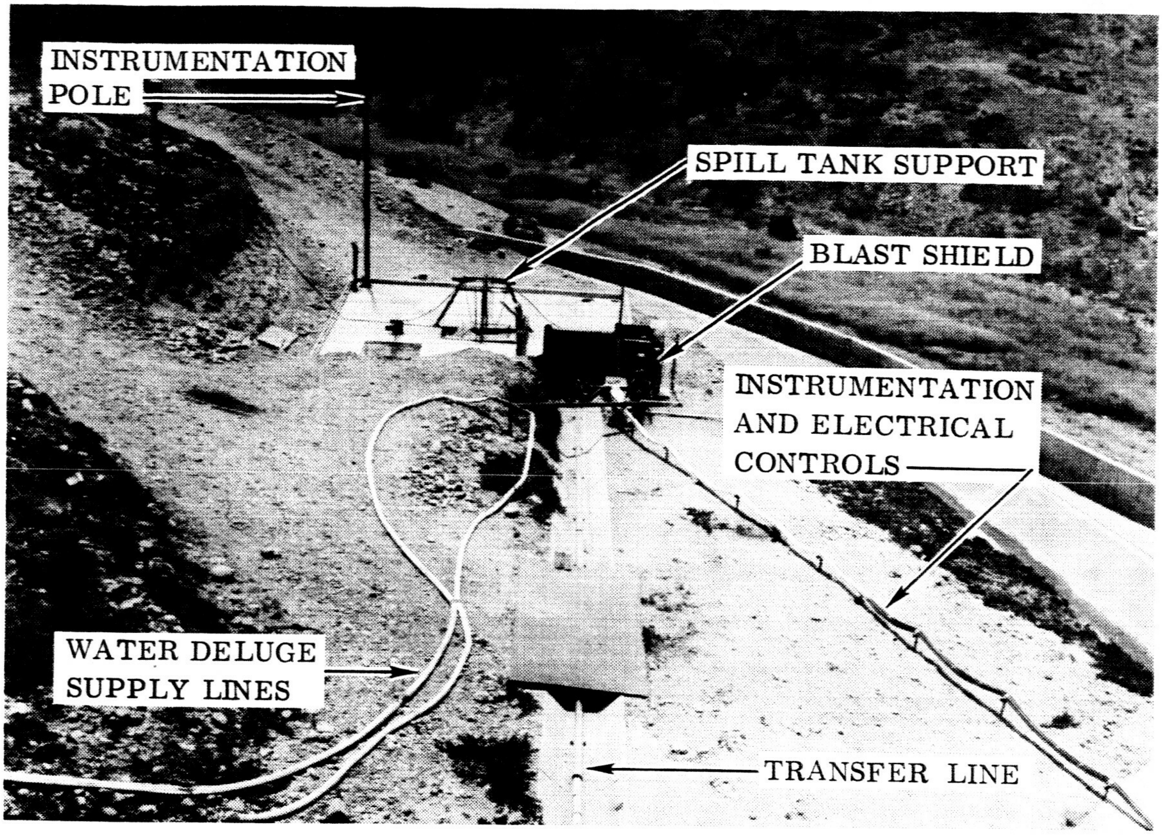


Figure 3-4. FLOX Transfer System

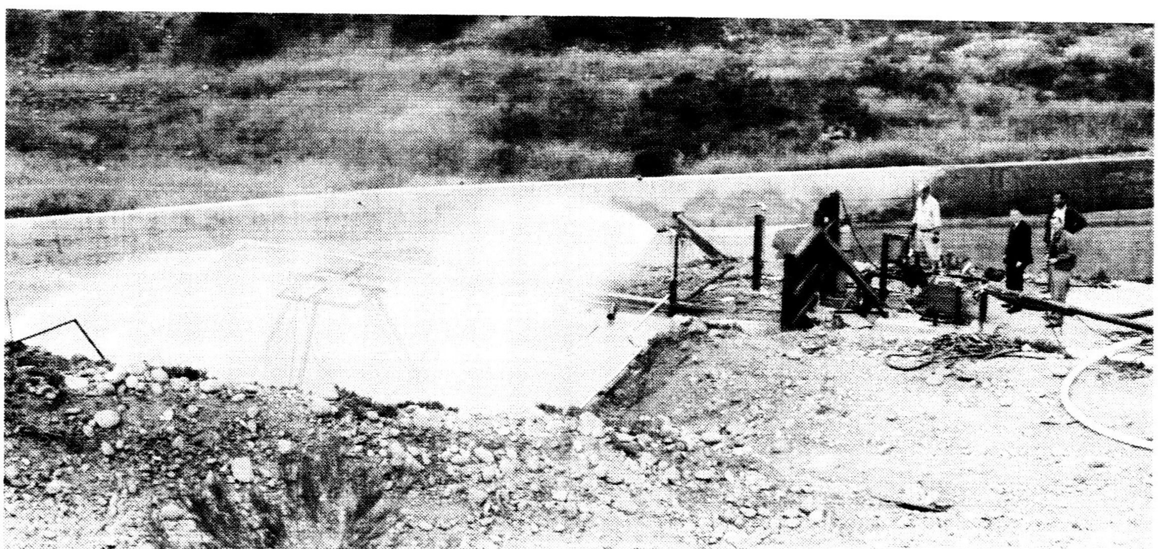


Figure 3-5. Water Deluge Checkout

The water deluge system consisted of two 2-inch nozzles located on opposite corners of the spill pad. Delivery rate for each nozzle at 150 psig was 278 gpm. The spray angle was 100 degrees. Figure 3-5 is a photo of deluge system checkout. Since after-fire damage was minimal, the deluge system was not used on most tests.

The water fog system was used to determine the effectiveness of water fog on a FLOX spill in suppressing source strength and downwind concentration. A throttling valve and flowmeter were installed in the manifold to control water flow. A single nozzle was used at the corner of the spill pad adjacent to the 4 x 4 x 4 ft basin.

4. FLOX Spill Tanks and Support. (See Figure 3-6.) Four sizes of FLOX spill tanks were fabricated from 6061-T6 aluminum. The cylindrical tanks were sized for 100-, 500-, 1000-, and 3000-lb test volumes of FLOX and 10 percent ullage. Each tank was fitted with a 1-inch FLOX inlet stand pipe and a 3-inch vent outlet connection. The vent outlet was placed at the height of the liquid fill volume, ensuring an accurate test volume. A 3-inch port and plug were provided in the top of each tank to facilitate cleaning.

Each spill tank was LOX cleaned and inspected before delivery to the test site. During the cleaning inspection, however, several tanks were found to have grease pencil and felt marking pencil stains on the interior surfaces. Since the stains were inaccessible to cleaning tools it was decided to test the stains for compatibility in the fluorine laboratory. Three pieces of scrap 6061-T6 aluminum were stained by grease pencil and felt marking pencil and then put through the same cleaning cycle as the tanks. The stains remained, and the pieces were tested in F_2 environment. The first test piece was subjected to 100 percent F_2 gas at 5 psig for 10 minutes, the second was placed in a 50 percent FLOX mixture at 5 psig for 15 minutes, and the third was left overnight in 100 percent F_2 gas at 5 psig. There was no reaction. It was concluded that the cleaning was adequate and that passivation received by the tanks during filling would be adequate. Subsequent testing proved this to be correct.

The FLOX spill tanks were supported above the spill basin by a removable 3-inch-diameter pipe frame. The frame was designed to support any of the four tank configurations. All sections of the pipe support were open to each other so that the entire assembly could be water cooled.

5. FLOX Tank Spill System. (See Figure 3-7.) A linear shaped charge was selected as the optimum method for detaching the tank bottom and

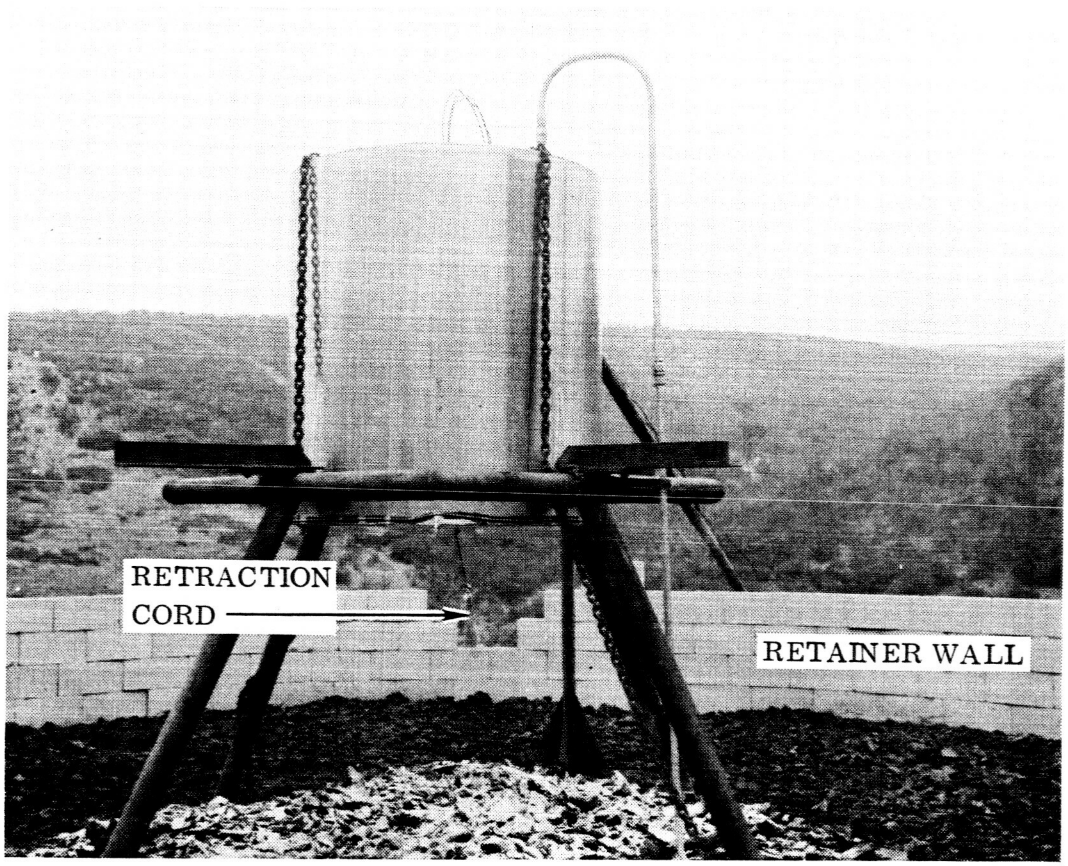


Figure 3-6. FLOX Spill Tank and Support

initiating spill. The shaped charge chosen was 20-grain-per-foot, lead-covered RDX with a detonation rate in excess of 6500 meters per second. A single wrap of the linear shaped charge was taped around the spill tank. A blasting cap detonated the charge. This method was successfully tested with a prototype tank and LN_2 prior to the first FLOX spill.

In order to obtain proper oxidizer/fuel mixing, it was necessary to prevent the bottom of the spill tank from dropping onto the fuel in the spill basin. An elastic retraction cord was attached to the bottom of the spill tank and stretched to the edge of the concrete basin as shown in Figure 3-6.

6. Spill Tank Vent Line. (See Figure 3-7.) The spill tank vent line was fabricated from a 3-inch-diameter copper tube designed to mate with any of the four tank configurations. This line extended past the edge of the 30 x 30-ft pad to prevent premature liquid or gas spillage on the fuel. After several combustive spill tests, a water scrubbing spray was added near the end of the vent line to suppress any FLOX vapor which otherwise might have been picked up by instrumentation.

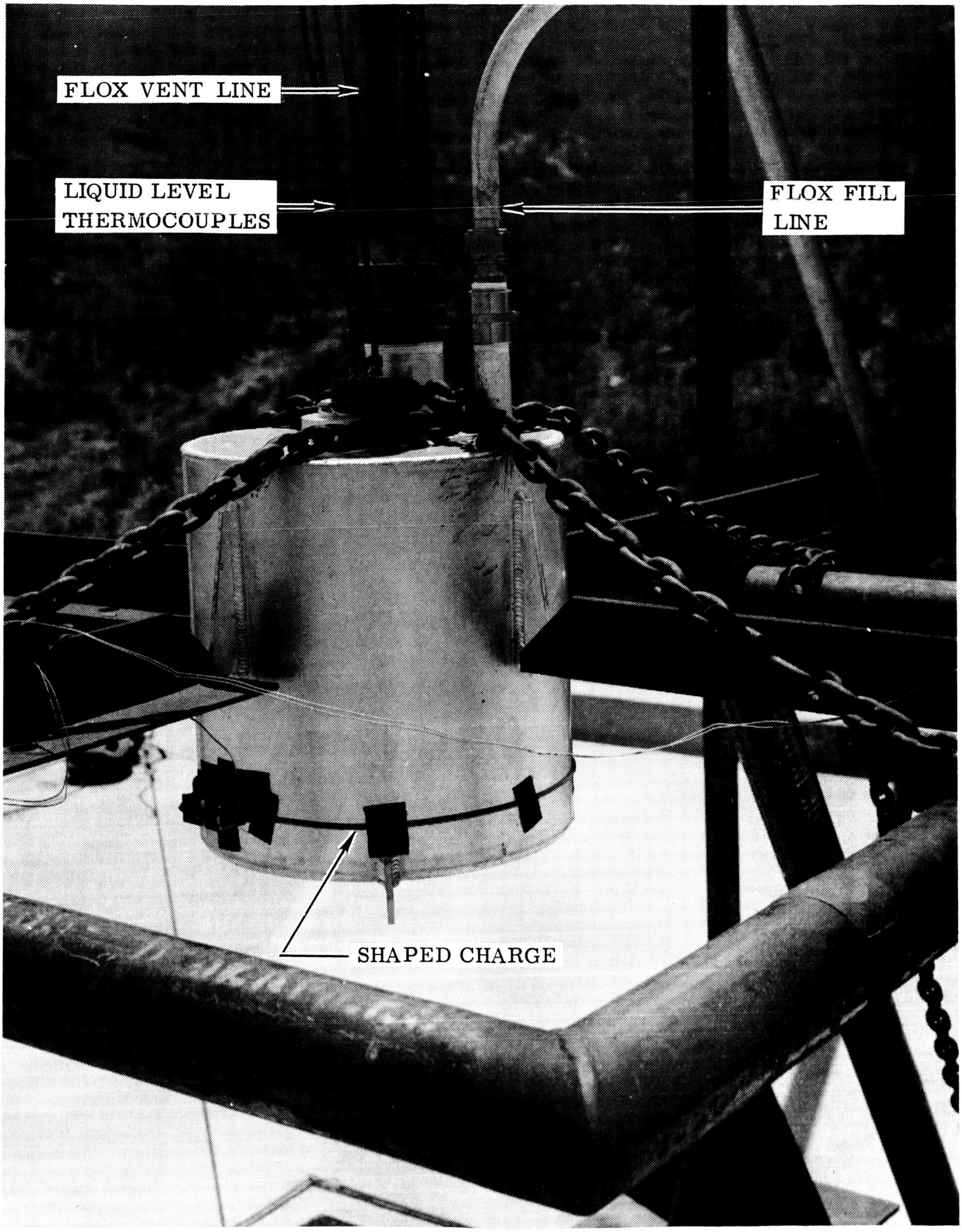


Figure 3-7. FLOX Tank Spill System

7. Temperature Instrumentation Pole. A 60-ft instrumentation pole was installed to carry fireball temperature sensors. The pole was designed for a 1g side thrust constant load, and was made of four decreasing-diameter, schedule-40, carbon-steel pipes. A hinged base plate and lifting lug were attached for erection.

Temperature sensors consisted of 10 chromel-alumel thermocouples spaced at 6-ft intervals on the pole. Thermocouples were attached to the pole with 0.047 CRES wire.

8. Fuel Transfer System. The fuel transfer system consisted of a 55-gallon drum, transfer line, and control valve. Fuel was transferred from the existing fuel farm to the storage drum through a 3/4-inch, schedule-40, carbon-steel pipe. The drum was located on a hill above the spill basin. Transfer to the spill basin was by gravity flow through the 1-inch valve and 1-1/4-inch CRES tube transfer line. Nominal flow rate was 30 gpm.

9. Electrical Controls. (See Figure 3-8.) Controls for the FLOX transfer line valve, water deluge and fog system, spill system, and fuel transfer system were located on a panel in the blockhouse. Figure 3-8 is a photo of the panel.

10. Instrumentation. (See Figure 3-9.) The liquid-level instrumentation system consisted of thermocouple sensing points, ice reference bath, blockhouse signal cable, and single-point strip recorders with a 1 cps response rate.

The fireball instrumentation system consisted of thermocouple sensing points, ice reference bath, signal cable, amplifier, signal conditioning equipment, and an oscillograph with a 1200 cps response rate.

Overpressure instrumentation was obtained on loan from Edwards Rocket Base, Project Pyro, which is under the technical direction of NASA MSFC. The overpressure instrument was located 39-1/2 ft from the center of the spill basin. The system consisted of the overpressure transducer, signal cable, amplifier, and an oscilloscope. The oscilloscope display was filmed at 1800 inches per minute. Full-scale deflection was 1.1 psig.

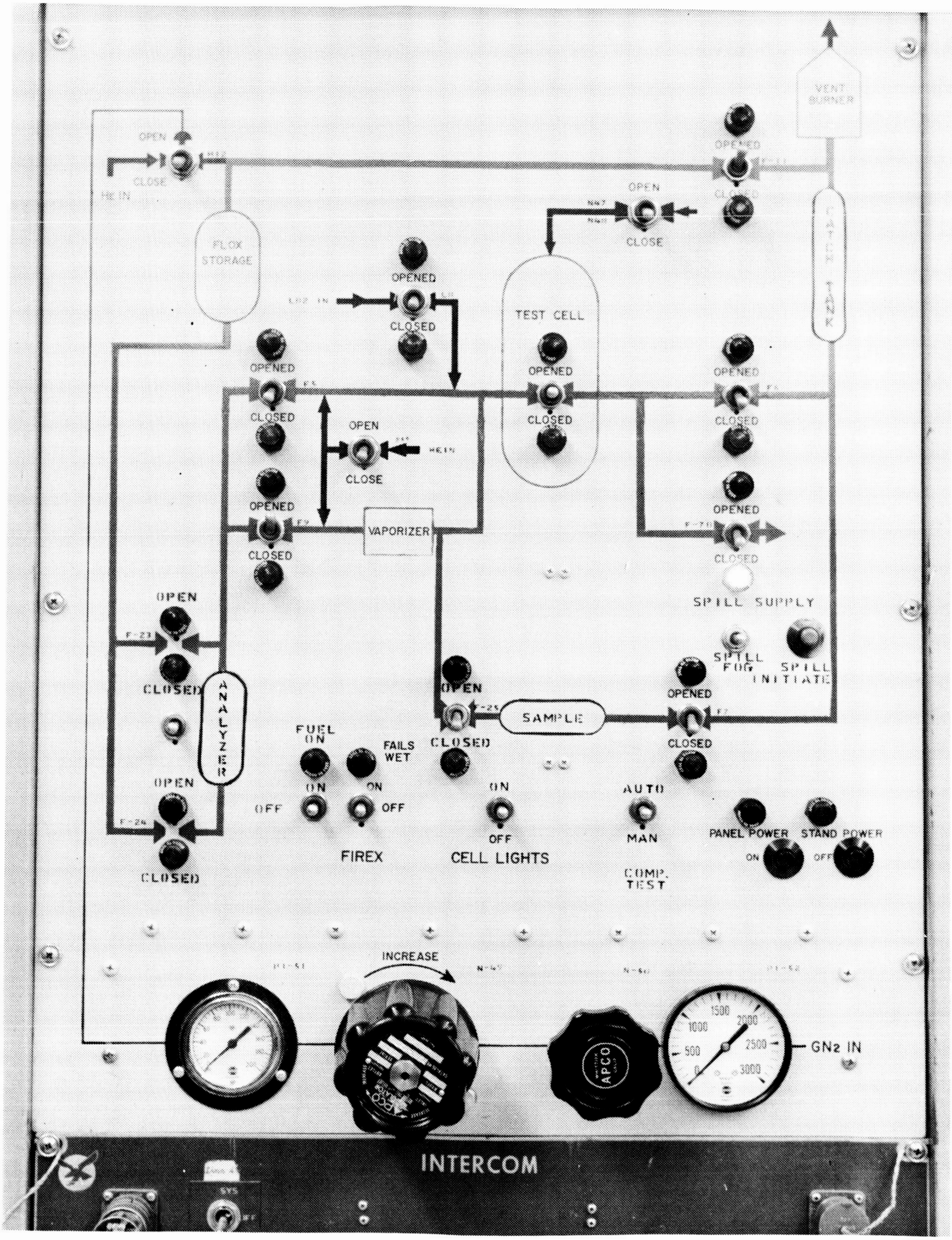


Figure 3-8. FLOX Test Panel

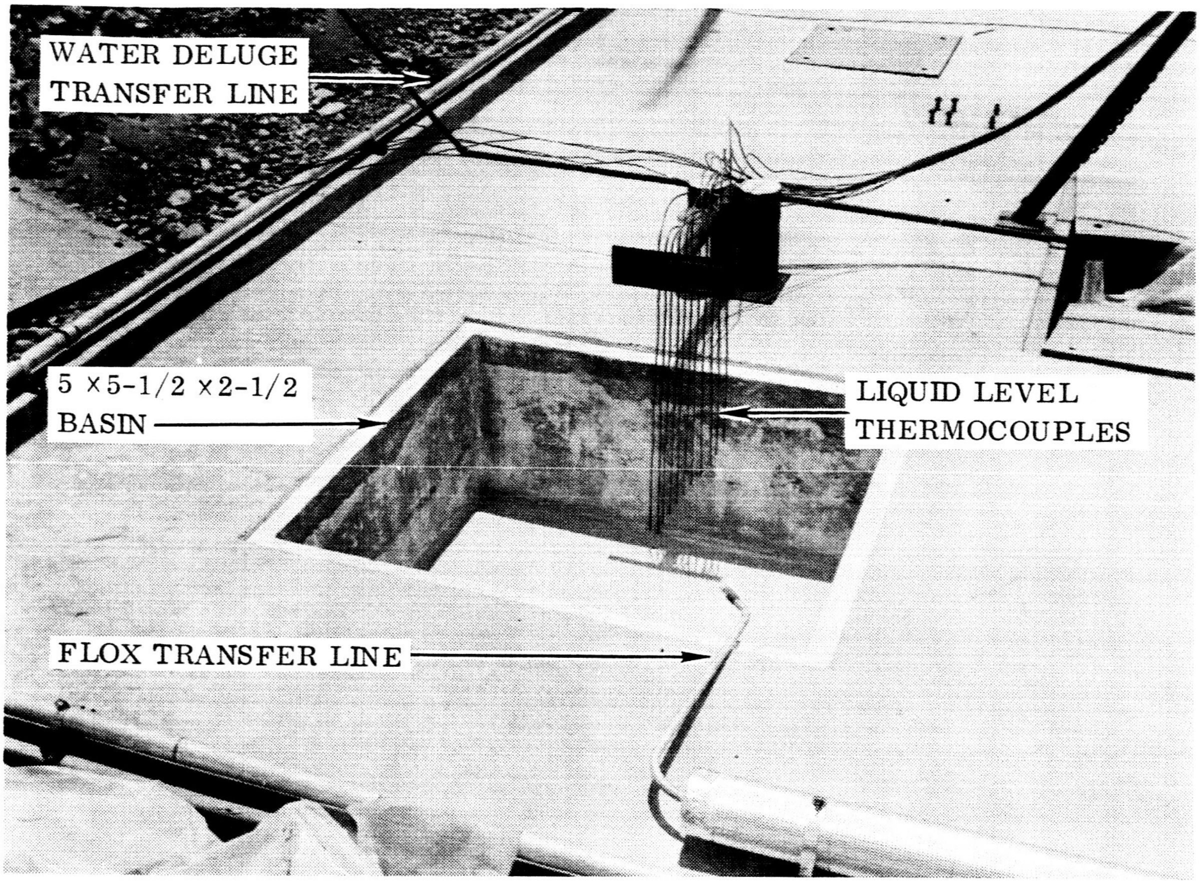


Figure 3-9. FLOX Test Instrumentation

Figure 3-10. Sycamore Test Site

IV FLUORINE AND HYDROGEN FLUORIDE SENSING INSTRUMENTATION

The development, procurement, and evaluation of seventeen fluorine and hydrogen fluoride sensors in the ppm sensitivity range was a separate, yet integrated, task in the basic Sycamore Test Site Fluorine Diffusion Program.

The requirement for these instruments was created by the Citation Permit, which required that:

> "Pollution sampling and detection instrumentation shall be provided to record, document, and maintain records of peak concentrations and total quantities (as a function of time) of the pollutant passing the boundaries of Sycamore Canyon."

The selection of instruments to fill this requirement was restricted because no instruments in the sensitivity range of interest were available for portable, remote operation; the Citation Permit maximum allowed doses were of 5 ppm-min F_2 and 50 ppm-min HF. Two manufacturers, Davis Instrument Co., and Tracerlab responded to a requirements specification for hydrogen fluoride and fluorine respectively. In addition, Convair designed, developed, and built an electrochemical instrument for fluorine and packaged a potassium iodide dosimeter for fluorine and hydrogen fluoride measurement. The instruments are of different sensitivities in order to provide the mix of sensitivities desirable in a field diffusion test. Once the feasibility of the instruments was determined in early tests, the instruments were deployed to provide a comparison with diffusion prediction values and with data obtained from FP measurements.

This paragraph describes the instruments, the calibration procedures, summarizes the operational experiences, lists criticisms, and evaluates the overall suitability of the instruments for the purpose stated in the Citation Permit. (All of the field measurements obtained with these instruments are displayed in Section V Figures 5-65 through 5-84.)

A. Description

1. Davis HF Indicator-Recorder. (See Figure 4-1.)

The Davis HF Indicator-Recorder was manufactured as Model 11-7010-RP Special by Davis Instruments Division of Davis Emergency Equipment Co., Inc., Newark, New Jersey. The instrument is 16-in. wide, 24-in. high, 12-in. deep, and weighs 55 lb. The nominal range of the instrument is 0 to 160 ppm fluoride full-scale with a response time of 90 percent reading in 1 minute. Detection by the instrument of airborne contamination is performed by measuring the electrical conductivity of a stream of water in contact with the atmosphere. The instrument, therefore, is sensitive to all atmospheric contaminants that form conducting ions in the water stream. These include fluorine, hydrogen fluoride and other inorganic fluorides, nitrogen oxide, and carbon dioxide. However, because the instruments were adjusted to zero background and because of the low concentration of nitrogen oxides present in the atmosphere, the instrument actually functioned only as a total fluoride detector for this test. In operation, the instrument continuously draws in atmosphere at a rate of 930 cc/min. and mixes it with a stream of water in the conductivity cell. A constant potential of 24 vac is maintained across a pair of electrodes in the cell, and the current passed by the sample/water mixture is rectified; the output is recorded on a strip-chart recorder. The effluent from the conductivity cell is purged through a monobed deionizer, where all ions dissolved from the atmospheric sample are removed. The purified water is then recirculated through the conductivity cell, thereby providing continuous analysis. Instrument power is provided by a set of eleven 1.1-volt rechargeable Yardney silcad alkaline batteries connected in series. The conductivity cell output is recorded on a 10 mv Rustrak recorder with a 2.3-inch strip chart.

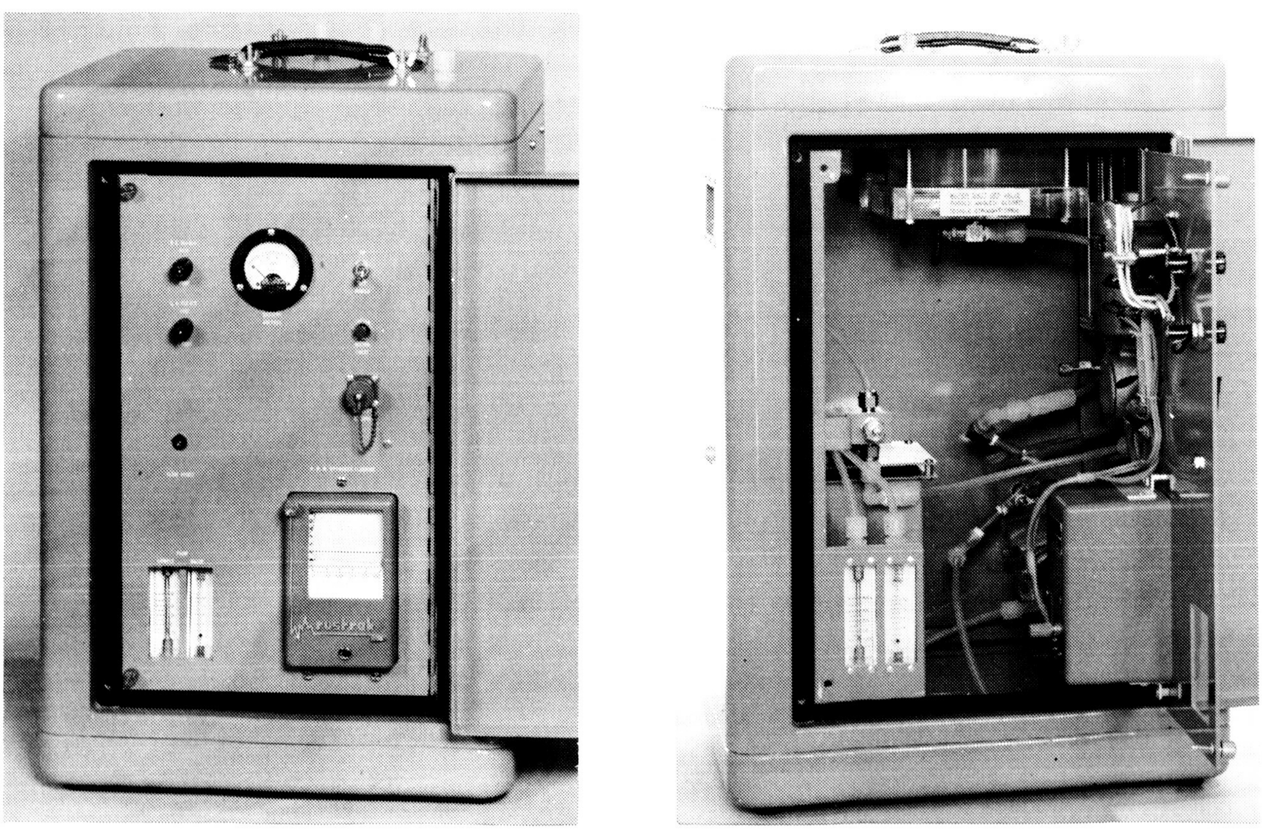


Figure 4-1. Davis HF Indicator-Recorder

2. Tracerlab Fluorine Indicator-Recorder. (See Figure 4-2.)

The Tracerlab Model FM-2 Fluorine Indicator-Recorder was manufactured by Tracerlab Dividion of Laboratory for Electronics, Inc., Waltham, Massachusetts. The instrument is 6-1/2-in. high, 15-1/2-in. wide, 9-1/2-in. deep, and weighs 20 lb. The sensing element of the instrument is a krypton-85 quinol clathrate. On exposure to a strong oxidizer such as fluorine, the quinol is oxidized to quinone, destroying the hydrogen-bonded clathrate and allowing the radioactive krypton-85 to be swept into a radioactivity counting chamber. The instrument is also sensitive to solvents of quinol such as water and acetone since they also destroy the hydrogen bonded clathrate. The instrument is equipped with a mechanical gate over the counting chamber, which can be adjusted to provide a constant sensitivity to fluorine at different relative humidities. According to the instrument manual, the sensitivity is constant up to 45 or 50 percent RH, depending on the individual clathrate cell, and then increases up to 90 percent RH, above which the instrument should not be used. In operation, atmosphere is drawn through a front panel inlet port at a rate of 100 cc/min ; the sample passes through the clathrate cell, through the counting chamber, and is expelled through a front panel outlet port. A controlled bleed-in port is provided between the counting chamber and the constant speed pump to allow regulation of the sample flowrate. The output of the Geiger-Muller counting tube is amplified and fed to a front panel meter and a 100 μa Rustrak recorder with 2.3-inch strip chart. A resistive divider circuit operated by a function switch provides full-scale meter deflection for 10K, 30K, and 100K counts per minute, which correspond to 10, 22 and 120 ppm by volume, respectively. The instrument power is supplied by six 12-volt rechargeable dry cell batteries. A battery charger in the instrument allows recharging from a 110-vac line.

3. Convair Chemical Fluorine and Fluoride Dosimeter. (See Figure 4-3.)

The Convair Model 00509 Chemical Fluorine and Fluoride Dosimeter was designed and assembled by the Convair Division of General Dynamics Corporation, San Diego, California. The instrument is 14-in. wide, 12-1/2-in. high, 8-1/2-in. deep, and weighs 24 lb. The instrument operates as an absorber of atmospheric contamination and gives only the total integrated dose for the test run. In operation, atmosphere is pumped through a cylinder containing an absorber solution of 1 percent potassium iodide and then expelled through the outlet tubing. The potassium-iodide solution absorbs both fluoride and fluorine; the absorbed fluorine is reduced to fluoride, an equivalent amount of iodide being oxidized to iodine in the process. At the conclusion of a test run, the absorber solution is removed from the instrument and analyzed for total fluoride and iodine. The

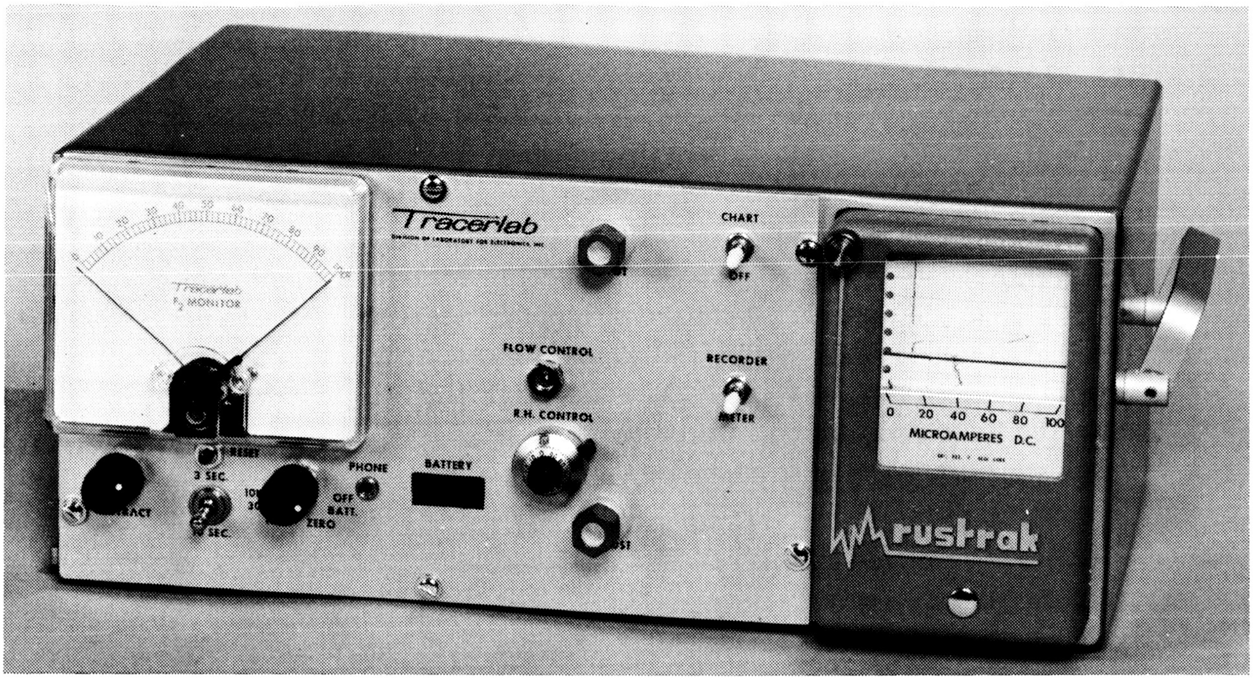


Figure 4-2. Tracerlab Fluorine Indicator-Recorder

amount of fluorine absorbed is proportional to the amount of iodine present, and the total fluoride present minus the fluorine absorbed is proportional to the amount of hydrogen fluoride absorbed. The nominal instrument sampling rate is 220 cc/min with a Mast Model AP-X positive displacement pump. Power for the instrument is provided by six 2-volt rechargeable lead-acid batteries in series.

4. Convair Electrochemical Fluorine Indicator-Recorder. (See Figure 4-4.)

The Convair Model 00510 Electrochemical Fluorine Indicator-Recorder was designed and assembled by the Convair Division of General Dynamics Corporation, San Diego, California. The instrument is 14-1/2-in. wide, 10-1/2-in. high, 11-in. deep, and weighs 32 lb. The sensing element of the instrument is a silver, silver-chloride, chlorine galvanic cell. The nominal range of the instrument is 0 to 5 ppm with a response of approximately 90 percent in 30 seconds. The cell consists of a glass tube in which a platinum gauze electrode and a silver wire electrode are immersed in a lithium-chloride solution. When an atmospheric sample is bubbled through the lithium-chloride solution, any fluorine present will oxidize an equivalent amount of chloride to chlorine. The EMF developed by the cell is a function of the partial pressure of chlorine and, therefore, of the partial pressure of fluorine in the atmospheric sample. The EMF developed in

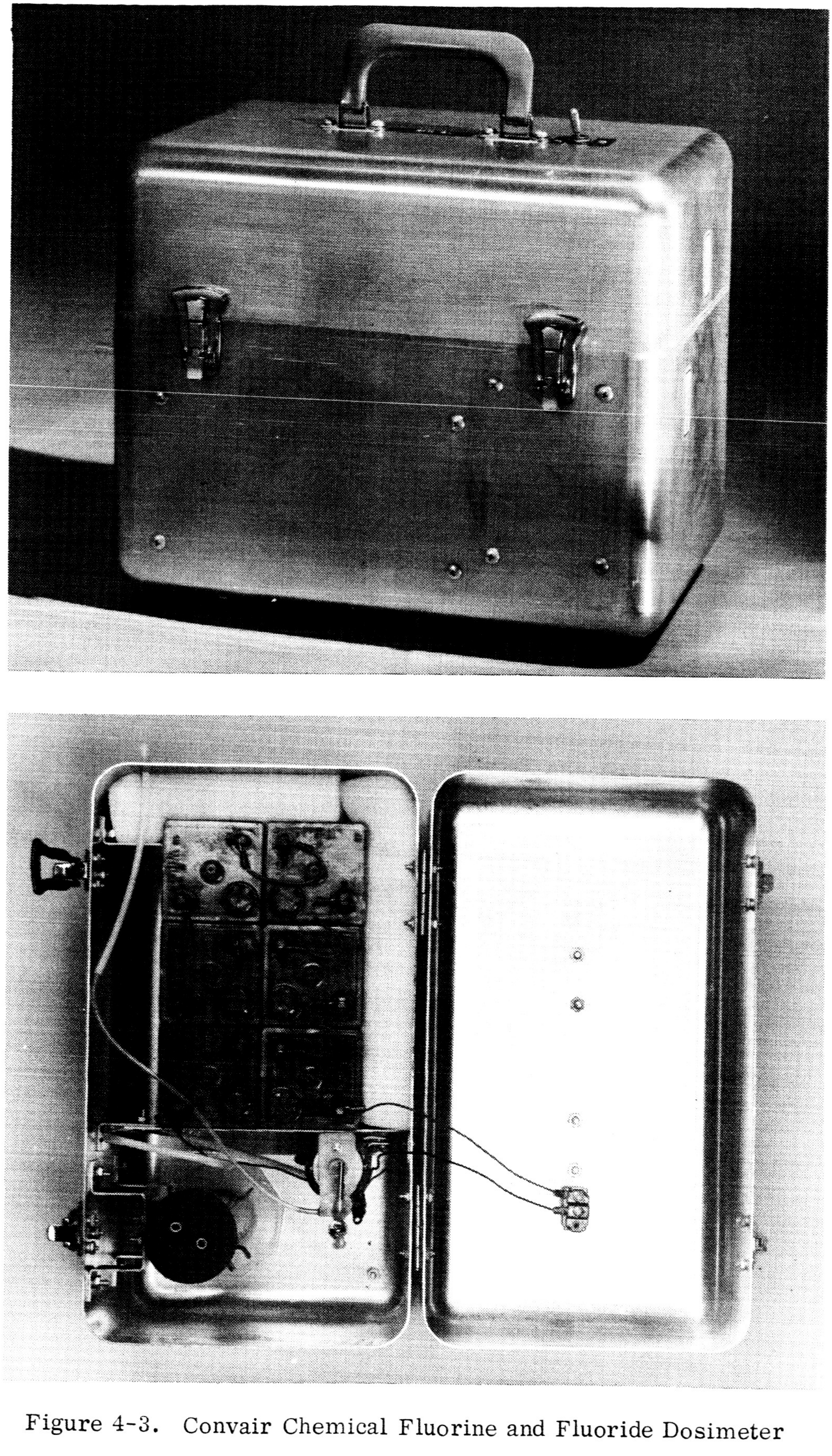


Figure 4-3. Convair Chemical Fluorine and Fluoride Dosimeter

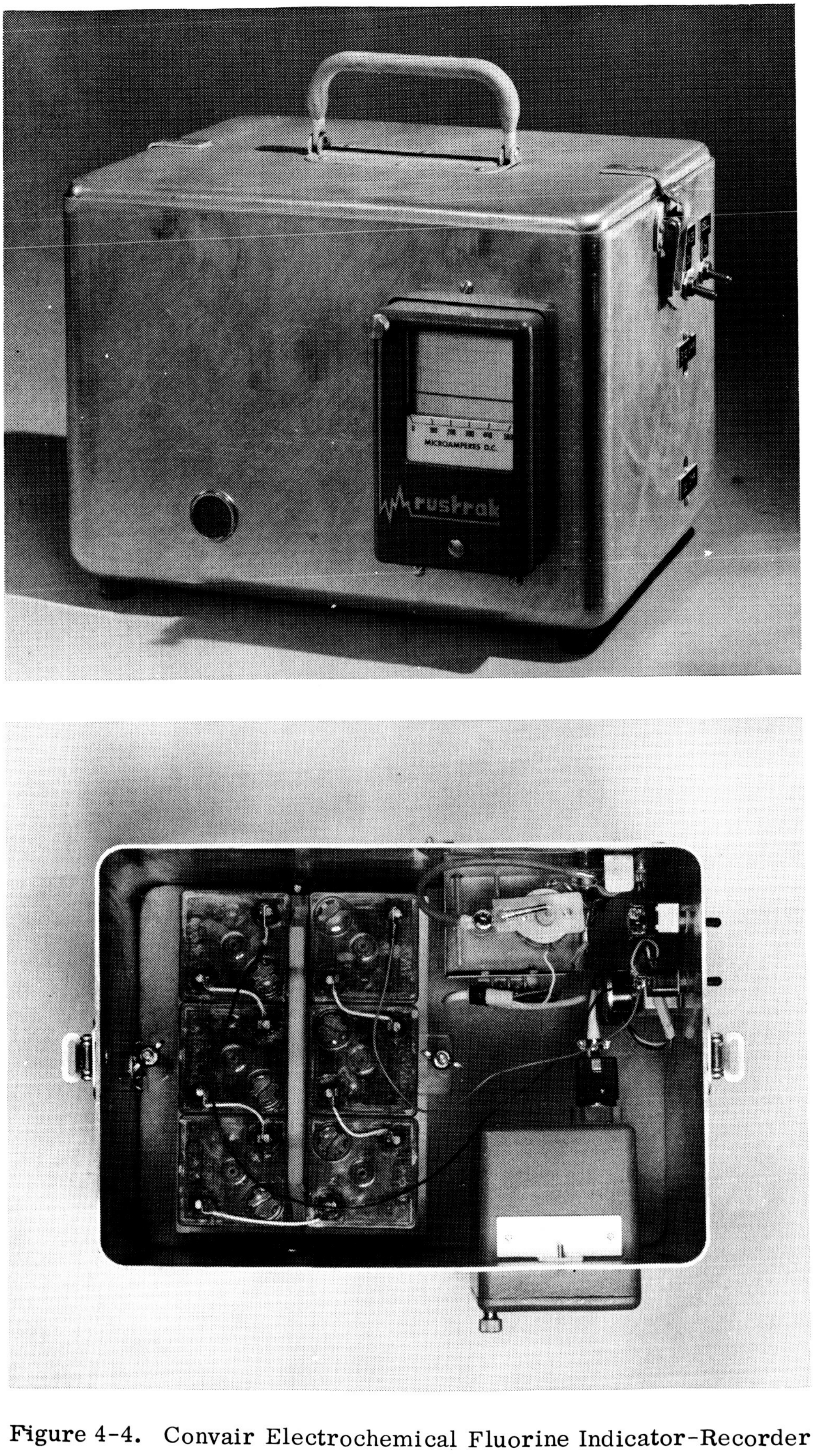


Figure 4-4. Convair Electrochemical Fluorine Indicator-Recorder

the cell produces a proportional electric current in the external circuit, the value of which is continuously recorded on a strip-chart recorder. In absence of fluorine, the cell still produces a small EMF due to the difference in electrochemical potential of the silver and platinum electrodes, but this is nulled by a bucking voltage provided by a small battery. Atmosphere is drawn through the cell at a nominal flow rate of 220 cc/min. by a Mast AP-X positive displacement pump, and the cell output is recorded by a 20 μa Rustrak recorder with a 2.3-inch strip chart. Power for the instrument is supplied by six 2-volt rechargeable lead-acid batteries connected in series.

B. Calibration

An initial calibration was performed on each of the instruments prior to the first FLOX spill test, and periodic recalibrations were performed after approximately each three spill tests. Calibration included determination or adjustment of the instrument sampling rate and, except for the Convair chemical analyzers, determination of the instrument sensitivity in terms of parts per million of fluorine or of hydrogen fluoride per recorder scale division. The initial calibration included a determination of cross-sensitivity, that is, the sensitivity of the fluorine detectors to hydrogen fluoride and the sensitivity of the hydrogen fluoride detectors to fluorine. The initial calibration also included a determination of the spread of analyses of a single fluorine standard by the four Convair chemical analyzers.

1. Calibration Procedures

In the calibration procedures used, the instrument sensitivity was determined by allowing the instrument to sample a prepared static mixture of fluorine (or hydrogen fluoride) in nitrogen and recording the instrument output. The concentration of the prepared standard was determined by bubbling a known volume of the standard through 1 percent potassium iodide solution and determining the absorbed fluoride by colorimetric analysis. From the weight of fluoride absorbed and the volume of standard sampled, the concentration of the standard is calculated in ppm fluorine (or hydrogen fluoride) by volume. The calibration procedures for each of the four types of instruments are included in Appendixes I through IV.

2. Calibration Records

Individual calibration records were kept on each of the instruments. These records are included at the end of Appendixes I through IV.

Examination of the calibration records shows a considerable spread in instrument sensitivity for individual instruments, especially in the first several calibrations. Much of this is due to changes in instrument operation or malfunctions, as explained in the notes on the calibration records. However, where large changes in sensitivity occur without explanation, it is believed that the calibrations are incorrect rather than reflecting a real change in instrument sensitivity. It is believed the cause is incorrect analysis of the calibration standard used. This assumption is based on the fact that the difficulties in using a static standard for calibration were not realized at the start of the program; when these probelms became apparent and were corrected, fairly uniform sensitivities were obtained from calibration to calibration, as shown by the records for the last several calibrations.

3. Instrument Linearity. (See Figure 4-5.)

With one exception, all calibration runs were single point calibrations. That is, the instrument sensitivity was determined using only a single standard, and the instrument response was assumed to be linear over the full scale of the instrument. One calibration was, however, a two point calibration, and from the results the assumption of linearity of instrument response appeared to be justified.

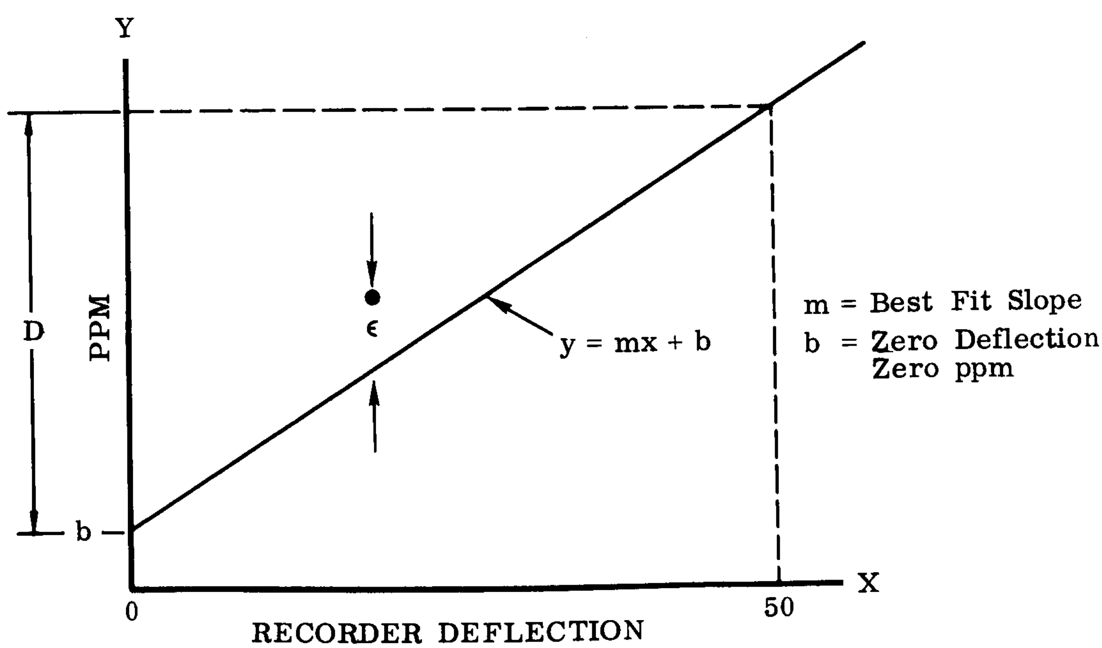


Figure 4-5. Instrument Linearity

This two point calibration was performed on the instruments during August 1965. The two concentrations utilized were 1.2 ppm (by volume) and 4.8 ppm for the Convair Electrochemical, 90 ppm and 147 ppm for the Davis, and 31 ppm and 54 ppm for the Tracerlab instruments. The two data points combined with the zero-deflection/zero-ppm point provided three points to check instrument linearity.

The least-squares linear-fit technique was used to determine the slope and offset of the best straight line through the three points.

Nonlinearity in percent of full-scale was then computed at each data point by dividing the difference between the actual data point and theoretical best-fit line by the full-scale recorder range and expressing this as a percentage.

Nonlinearity $= \frac{\epsilon}{D}$ (Expressed as a percentage)

The results are given in Table 4-1.

Table 4-1. Nonlinearity (% full scale)

INSTRUMENT	0 PPM	1.2 PPM	4.8 PPM
K1	+ 1.48	- 1.89	+ 0.41
K2	- 0.90	+ 1.20	- 0.34
K3	- 1.40	+ 2.40	- 0.64
K4	+ 0.07	- 0.09	+ 0.02
K6	- 4.64	+ 7.50	- 2.86
	0 PPM	90 PPM	147 PPM
D159	+ 1.42	- 3.18	+ 1.75
D160	+ 1.54	- 3.43	+ 1.89
D161	+ 1.13	- 2.62	+ 1.49
D162	+ 0.12	- 0.30	+ 0.18
	0 PPM	31 PPM	54 PPM
T2	+ 0.36	- 0.77	+ 0.40
T3	- 0.02	+ 0.04	- 0.03

The random positive and negative signs on the Convair electrochemical and Tracerlab instruments are characteristic of reasonable linearity. The consistently negative sign on the 90 ppm and positive on the 0 and 147 ppm of the Davis instruments are characteristic of either nonlinearity or possibly one calibration point concentration value being erroneous. Additional calibration points make this type of analysis more conclusive.

4. Discussion and Recommendations

The main difficulty encountered in the calibration procedures was due to the use of a prepared static standard. A static standard in the low ppm range of F_2 and HF is difficult to prepare accurately except by dilution of a more concentrated sample. It was necessary, therefore, to prepare an approximate concentrated standard, and then successively dilute it and check it with the instrument being calibrated until the concentration was within the range of the instrument. It was then necessary to determine the actual concentration of the standard by chemical analysis before proceeding with the calibration.

A second problem arises in the use of a static standard, due to absorption and desorption of fluorine and hydrogen fluoride from cylinder walls of the standard. The ratio of fluorine absorbed on the cylinder walls to that in the gas phase is a function of the concentration of fluorine in the gas phase and the total pressure of the standard. Further, the rate for the system to achieve equilibrium appeared to be quite slow. The net effect is that as the standard is used to calibrate a set of instruments, the concentration of the standard is changing. It was necessary, therefore, to determine the concentration of the standard both before and after a calibration run, and also to limit use of the standard in a calibration run to 25 percent of the available pressure in the cylinder.

It is believed that the difficulties encountered using a static standard could be obviated by using a metered flow system for the sensitivity determinations. This would involve metering separate sources of fluorine (or hydrogen fluoride) and nitrogen into a mixing tube, and allowing the instrument being calibrated to sample the effluent from the tube. The concentration of the standard may be adjusted to and maintained at any desired value by regulating the flowrates of the nitrogen and fluorine supply. The amount of standard available for a calibration run would be limited only by the supply of fluorine and nitrogen. Instrument linearity could be easily determined. Finally, the concentration of standard being used to calibrate an instrument would be known immediately from the flowrates while the calibration is being performed, rather than at a later time when the analysis of the standard had been completed. This way, the performance of an instrument could be immediately compared to previous calibrations, and required adjustments to the instrument made during the calibration.

C. Placement

The placement of fluoride instruments was based on:

1. Predicted concentration level.
2. Wind direction tempered by the effect of stability on plume trajectory.
3. Sensitivity of the instrument.
4. Portability of the instrument.
5. Confidence levels in the instrument as experience was gained.
6. Citation permit requirement to monitor boundary conditions.

Since the duty cycle of the instruments was a maximum of four hours and placement required about two hours because of setup adjustments and the inaccessibility of some locations, the preselection of location was, of necessity, intuitive. A best estimate of wind direction two to three hours hence was made on the basis of pretest wind trends. Instrument locations were selected to bracket the forecasted trajectory. The distance from the source was based on a diffusion prediction and sensitivity matching. Deployment for the early tests was close to the source (100 to 500 ft) to check response and general instrument functioning. As testing progressed, some instruments were moved out to as far as 5 1/2 miles. When the location was more than 1000 ft from the source, the locations coincided with tracer samplers so that comparative dose data could be obtained. Also, whenever instrument availability permitted, each location had a pair of instruments for comparative data. Twenty-eight such pairings resulted with comparative data produced on five occasions. Replotted data from the recorder chart for these five occasions are shown on Figures 4-6 through 4-10. The similarity of the plots with respect to time and the good agreement in magnitude are significant.

D. Summary

1. Operational Summary

Table 4-2 lists each type of instrument tested to facilitate a comparison of their weight, sensitivity, range, and linearity. The total operational time and problems associated with each individual instrument are included in Table 4-3. The last two columns in Table 4-3 reflect a rating of data recovered. The first of these columns was obtained by dividing the test

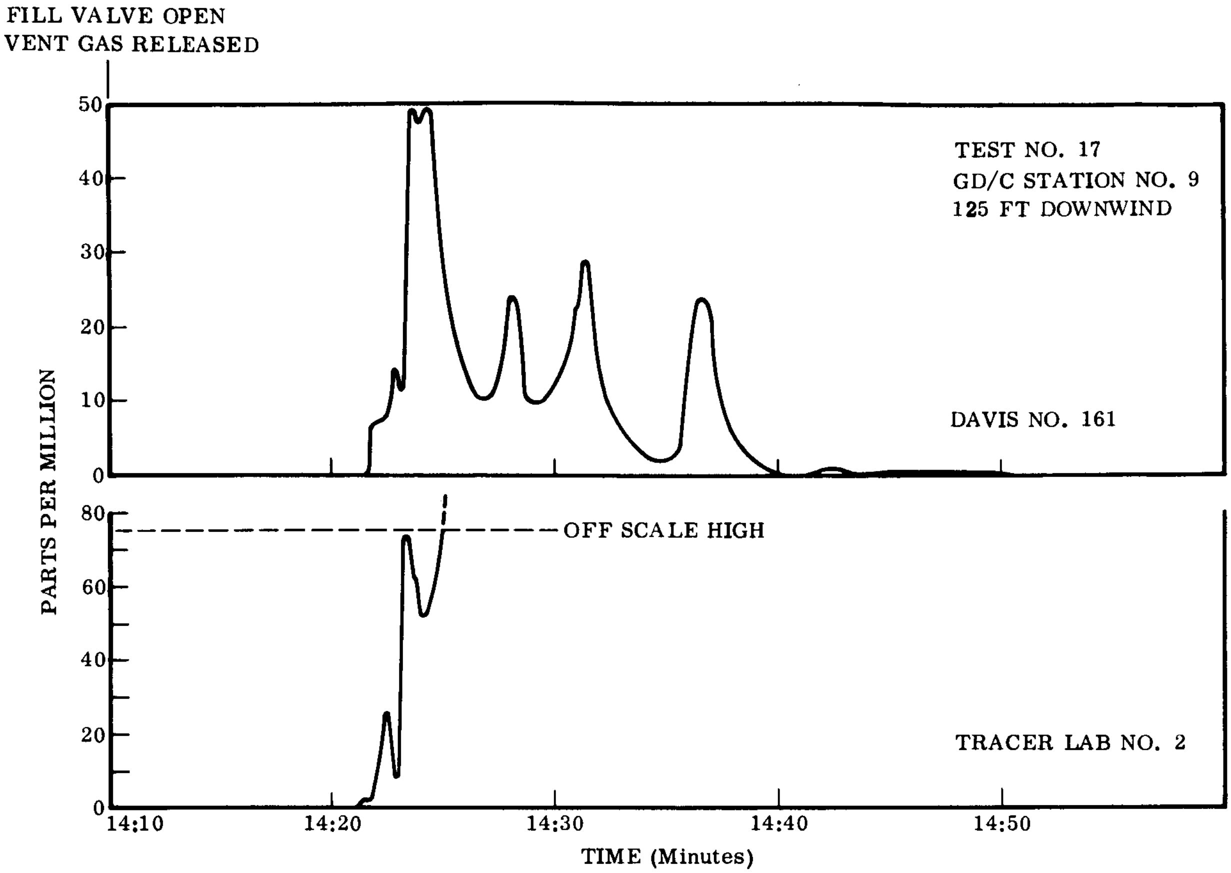


Figure 4-6. Test No. 17, Fluorine Instrument Response 125 Ft Downwind

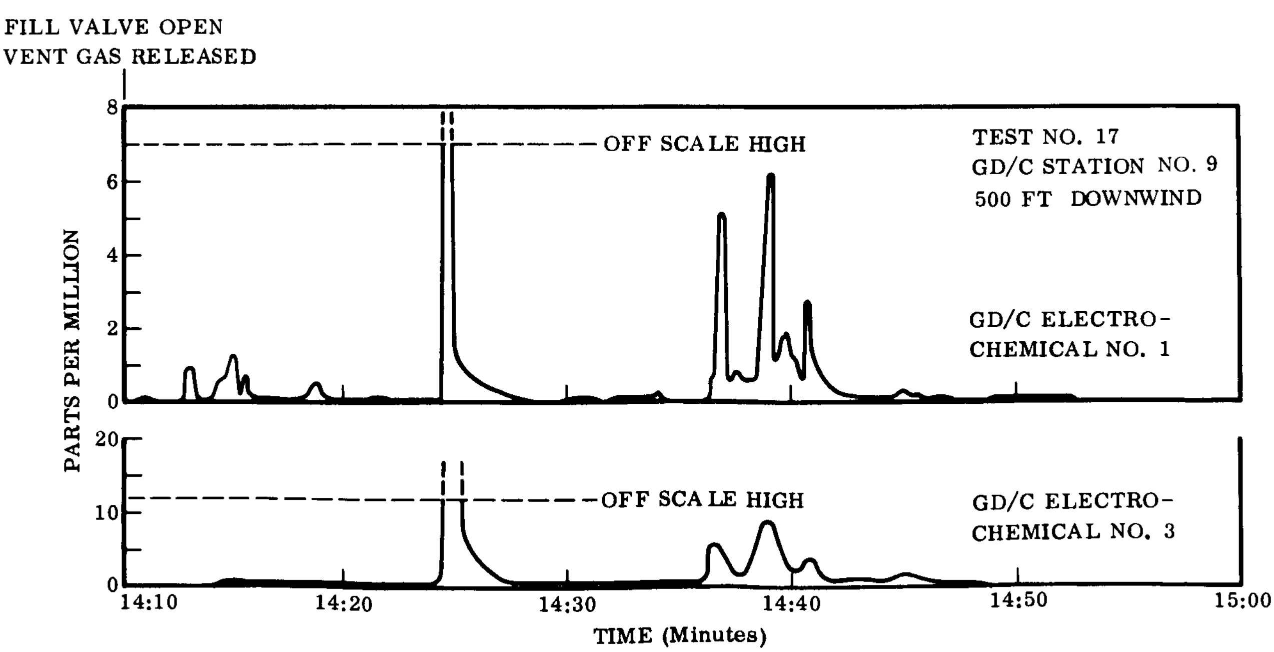


Figure 4-7. Test No. 17, Fluorine Instrument Response 500 Ft Downwind

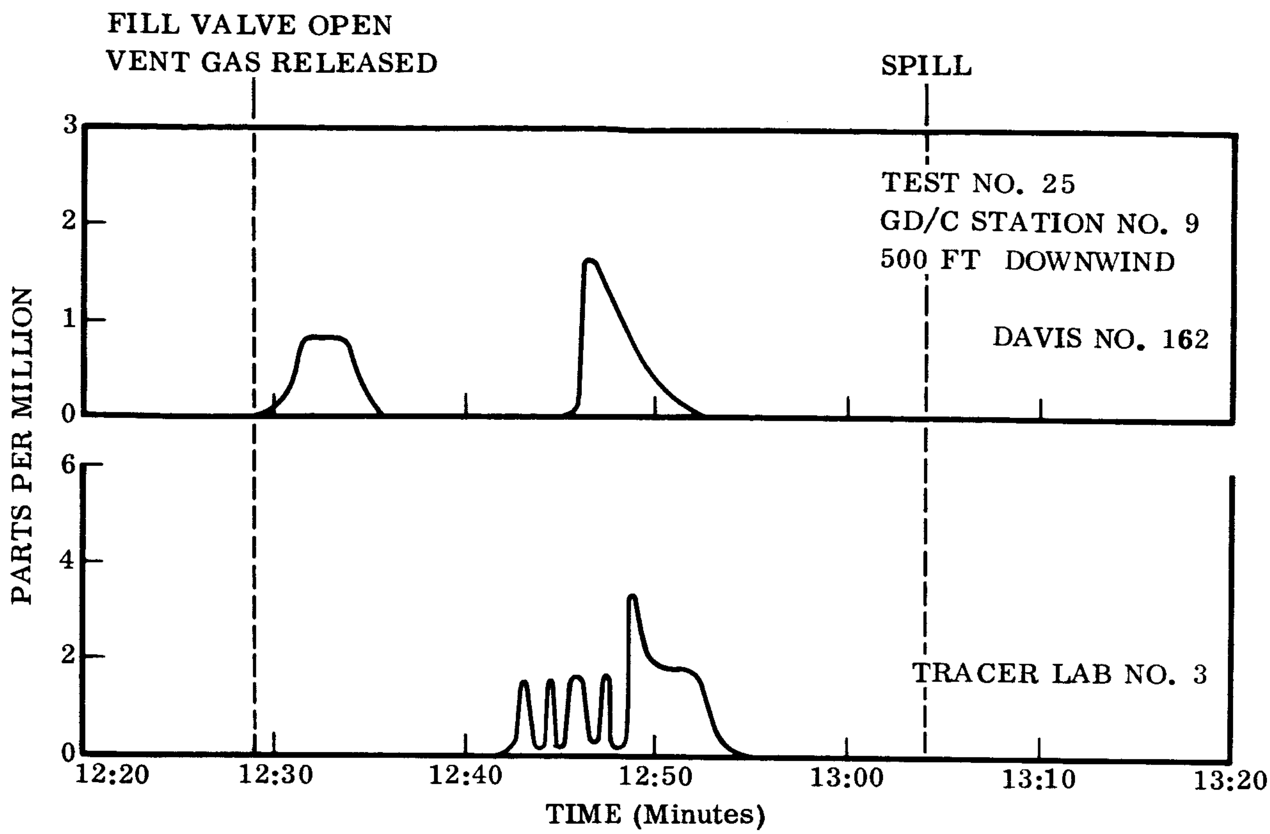


Figure 4-8. Test No. 25, Fluorine Instrument Response 125 Ft Downwind

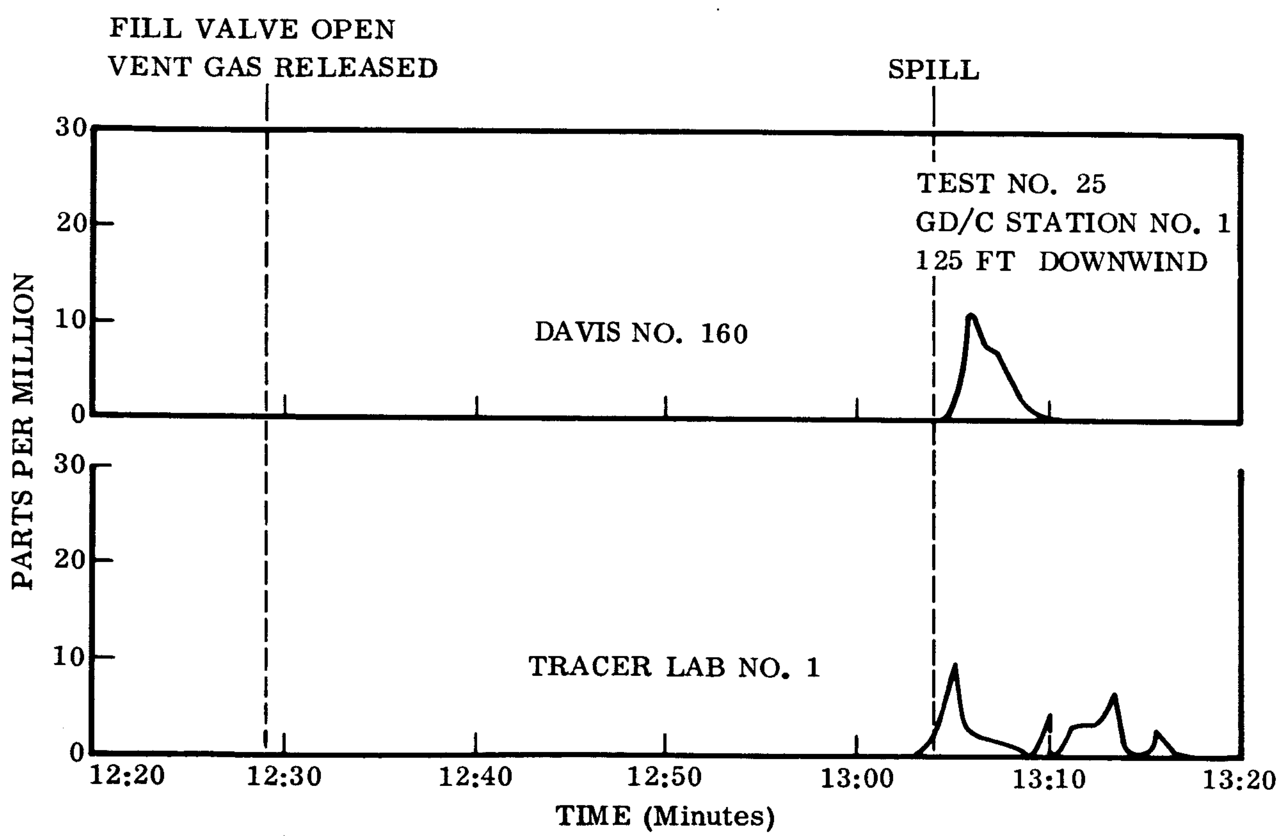


Figure 4-9. Test No. 25, Fluorine Instrument Response 500 Ft Downwind

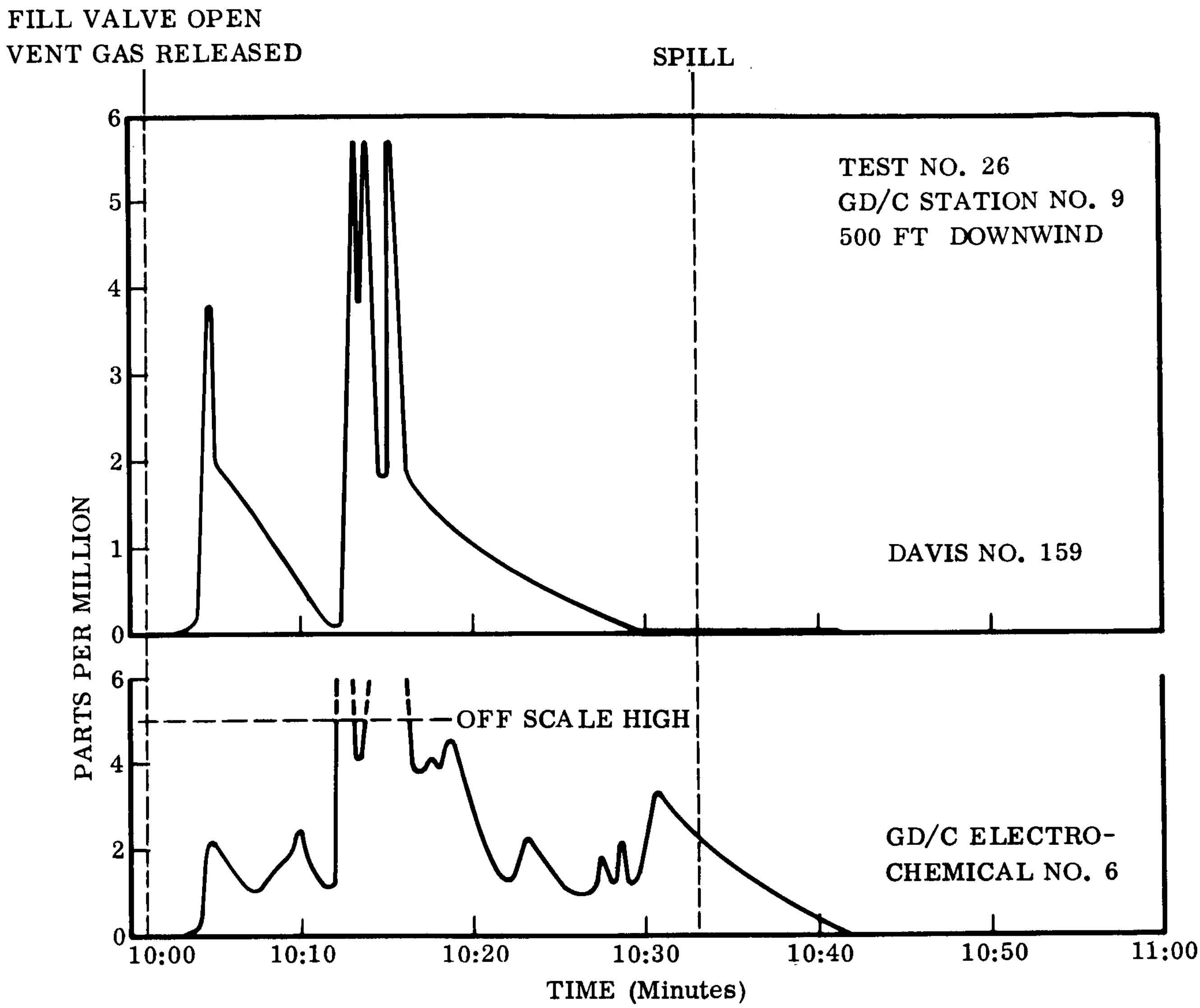


Figure 4-10. Test No. 26, Fluorine Instrument Response 500 Ft Downwind

data recovered by the total number of tests performed. The last column was obtained by dividing the test data recovered by only those tests where the instruments were placed in the field. Instruments with data in the category "some data collected" were rated as 50 percent data recovered for that particular test.

A speed - and voltage-vs-time graph, Figure 4-11, gives an indication of how the Davis instrument performed, since maintaining battery voltage was a problem. This data was obtained on one instrument for one test run only.

Table 4-2. Instrument Summary

TYPE	QUANTITY	WEIGHT (lb)	SENSITIVITY	RANGE	MIDRANGE LINEARITY (% F.S.)
Convair Chemical	4	24	F_2 & HF Separately	40-2000$^+$ ppm-min F_2 100-500$^+$ ppm-min HF	Not applicable
Convair Electro Chemical	6	32	F_2	0-10 ppm	1
TRACER LAB	3	20	F_2	0-120 ppm	3
DAVIS	4	55	F_2 & HF Indiscriminately	0-160 ppm HF 0-80 ppm F_2	2.5

2. Criticisms

The criticisms of the instruments are based on field applications, since no extensive laboratory evaluation was conducted.

a. Davis

1) Battery charging requirements are critical and the instruments did not maintain the 14.3 volts for 2 hours and then 12.1 volts for an additional 8 hours (refer to voltage graph).

2) Sample flowrate was difficult to maintain. The original pumps resulted in no flowrate from three units. New stainless steel pumps permitted flowrate adjustment, but the flowrate would change from the time the instruments were put in the field until they were picked up. This difference was noted 50 percent of the time.

Table 4-3. Instrument Operating Summary

RECORDER	TEST NUMBER 13 (oper hr / code)	14	16	17	18	19	20	21	22	23	24	25	26	27	28	total oper time hours	% data recovered all tests	% data only those instr used
R1	2.73	4.57	2.28	1.70	3.29	2.94	4.83	3.02	4.28	2.26	3.69	4.30	3.37	3.67	2.90	49.83	100	100
R2	4.33	4.73	2.23	1.83	3.35	2.68	1.92	4.64	4.30	3.82	5.20	4.22	2.25	3.87	4.85	54.22	100	100
R3	2.27	4.32	1.72	1.95	2.97	2.92	2.34	3.67	2.37	3.83	6.34	2.82	2.12	4.50	3.06	47.20	100	100
R4	2.42	4.32	2.17	1.95	2.87	2.70/QD	2.69	4.40	4.08	3.82	3.30	3.40	2.50	3.10	3.40	47.12	97	97
K1	2.27	4.62/QD	2.17	1.70	2.87	2.94	4.83	3.02	2.37	2.23	3.69	4.30	3.37	3.67	4.39	48.44	97	97
K2	2.27	4.93	2.17	1.83	3.35	2.68	1.92	4.64	4.30	3.82	5.20	4.22	2.25	3.87	4.85	52.30	100	100
K3	2.73	4.57/ZD	2.23/ZD	1.70	2.97/ZD	2.10	2.70	3.67	4.28	3.83	6.34	2.82	2.12	4.50	3.06	49.62	80	80
K4	2.32	4.77/ZD	*	1.70	2.45	2.92	2.69	5.07	4.08	3.82	3.16	4.34	2.26	3.09	3.40	46.07	87	93
K5	2.34/QD	4.70	2.28	1.95	**	**	**	**	**	**	**	**	**	**	**	11.27	[illegible]	88
K6	4.33	4.73	2.32	1.68	3.29	2.82	5.15	2.77	1.88	2.25	3.50	4.29	2.20	3.79	5.05	50.05	100	100
T1	2.8[illegible]/BD	4.57/BD	1.72	1.95	2.57	2.85/ZD	2.34	4.40/ZD	2.53	2.23	4.87	3.95	CC	CC	CC	36.83	53	57
T2	2.38/SS	4.40/BD	1.55	1.97	2.77	2.89	2.15/ZD	5.05	1.87	2.28	3.19	4.22	CC	CC	2.27	36.99	[illegible]	31
T3	2.42/SS	4.32/BD	1.77	1.97	2.64	2.70/ZD	2.34	4.40	2.48	3.25	2.97	4.24	CC	CC	2.37	37.87	73	85
D159	2.16/SS	4.42/BD	2.03/BD	1.97/BD	PP	PP	PP	PP	PP	PP	PP	4.25	2.20	4.42	2.27	23.72	37	69
D160	2.44/SS	4.34/SS	1.82/BD	1.70	2.45	2.85	2.34	2.74	1.87	2.30	2.50	3.92	2.18	5.43	1.37	40.31	87	87
D161	2.88/SS	4.48/BD	NBA	2.01	2.70	2.89	PP	PP	PP	PP	PP	4.30/BD	2.22	[illegible]	5.07	29.54	43	72
D162	2.21/QD	4.93/BD	1.67	1.70/BD	2.60	2.85	PP	PP	PP	PP	PP	4.20	2.23/ZD	3.89	4.39	30.67	47	70

QD - QUESTIONABLE DATA
ZD - ZERO DRIFT
BD - BATTERY DEAD
SS - SPEED TO SLOW

PP—FAULTY ALUMINUM PUMPS-NO SAMPLE FLOW
NBA—NO BATTERY AVAILABLE
CC—CLATHRATE CELLS HAD TO BE REPLACED

* — INSTRUMENT DROPPED-DOWN FOR REPAIR
** — RUSTRAK RECORDER BAD, NO REPLACEMENT

(dashed box) INSTR NOT PLACED IN FIELD FOR TEST
(solid box) NO USABLE DATA
(dotted box) SOME DATA COLLECTED- EITHER DATA IS QUANTITATIVELY IN DOUBT OR CANNOT BE TIME CORRELATED

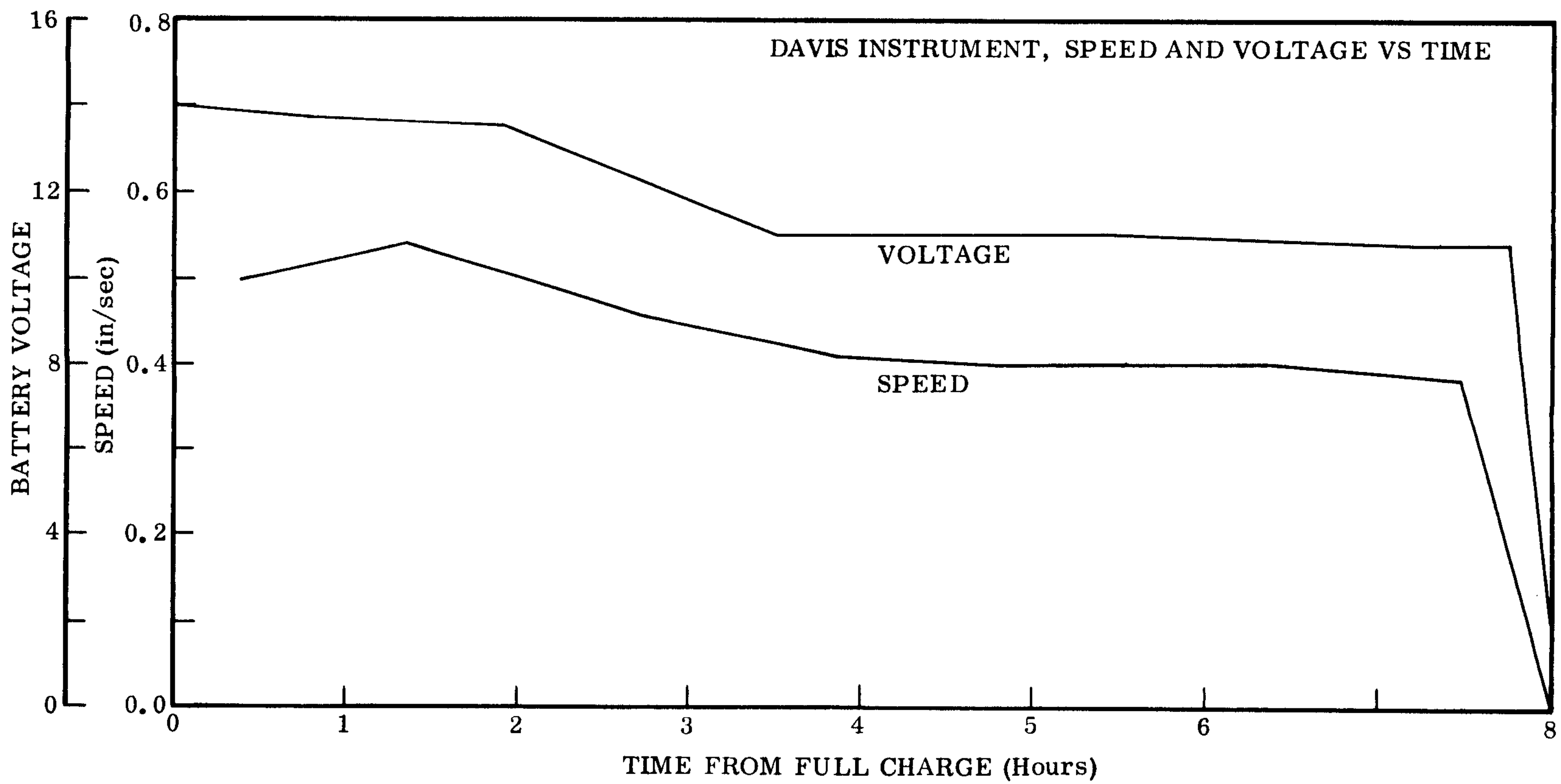


Figure 4-11. Davis Instrument Performance Curves

3) The instrument is too cumbersome for one man to handle easily in the field.

4) Recorder chart speed varies with battery voltage, and since voltage is not constant for a sustained duration, time correlation of data can become extremely questionable.

5) The instrument senses both fluorine and fluoride with different sensitivities for each. It is, therefore, impractical to use in a quantitative analysis if the sample is not known to be either fluorine or fluoride.

6) The internal components are not easily accessible to work on. Batteries in particular are difficult to remove. An interference problem prevailed between the water reservoir and the replacement pumps.

7) The screw type latches on the front two panel doors do not allow quick and easy access to the instruments.

8) Original recorder chart speed of 1 in/hr was too slow for the intended use. Chart speed was increased to 1/2 in/min to be compatible with the 4-hour duty cycle specified.

b. Tracerlab

1) The instruments would not maintain a stable zero level on the 10K scale in a 5 to 10 mph gusting wind. Zero level on the 30K scale drifted after being initially set, requiring initial zero to be set approximately 5 increments high.

2) Instruments shut off with the first off-scale-high indication. A short-duration high-concentration sample can turn the instruments off, thereafter yielding no data.

3) The clathrate cells were rated at 1 ppm for 6 months, but lasted only 12 tests plus 5 hours of calibration. Actual radioactivity of the cells had decreased less than 20 percent while the cell sensitivity to fluorine decreased to near zero. These findings were confirmed by Tracerlab in their tests of the returned cells with no explanation offered.

4) As mentioned in the instrument description, the fluorine sensitivity is a function of the relative humidity of the atmosphere being sampled. A mechanical gate is provided on the

counting chamber which can be adjusted according to the field relative humidity in order to maintain a constant sensitivity. This is not practical for field use since the field RH changes considerably during the test interval. For calibrations, since dry gases were used, the gate was left in the full-open position.

5) Original recorder chart speed of 1 in/hr was too slow for the intended use. Chart speed was increased to 1/2 in/min to be compatible with the 4-hour duty cycle specified.

c. Convair Electrochemical

1) Null potential adjustment resulted in excessive recorder zero drift.

2) Instrument response time had increased to 3 to 4 minutes and sensitivity had decreased by a factor of 2 to 5 at the third calibration. All cells were removed from the instruments and subjected to a cleaning and passivation process. This treatment brought the sensitivity and response times back to normal values. This treatment was incorporated into the calibration procedure.

d. Convair Chemical

1) These instruments absorb the sample which then has to be chemically analyzed for total fluorine/fluoride. There is no information provided on concentration vs time.

2) The colorimetric analysis used gives a negative slope of optical density vs fluoride concentration. At the low fluorine/fluoride concentrations experienced, small differences in color intensity are being measured in strongly colored samples. Because of the difficulty of discrimination, large percentage errors may occur.

3. Recommendations

a. Davis

1) Print the battery charging requirements on the case of the instrument in an appropriate location.

2) Provide more positive control of the sample flowrate.

3) Reduce the instrument weight.

4) Provide more stable voltage control for the chart drive.

5) Redesign the instrument case to provide easy access to all internal parts.

6) Change the screw-type door latches to a cam lock or similar arrangement.

b. Tracerlab

1) Provide stable zero-level control on all scales under varying field conditions.

2) Provide some means of continuous recording even though recorder goes off-scale high at times.

3) Provide some environmental control to eliminate the relative humidity variation effects.

4) Increase clathrate life to a practical value.

c. Convair Electrochemical

1) Establish more stable null potential adjustment and/or refined procedures for checking the instrument prior to placement in the field.

d. Convair Chemical

1) Provide a more accurate quantitative analysis technique for low dosages (less than 50 ppm-min) of both fluorine and fluoride.

4. Evaluation

Considering that all instruments used in this program were experimental and none had been used in a portable, field monitoring application previously, the results were quite satisfactory. In an evaluation of the relative usefulness of these instruments in monitoring concentrations in work areas, on boundary lines or other selected points, no standard of comparison exists. Accordingly, the evaluation must be based on a comparison of the results from the various instruments with predictions from the WIND equation and from the FP diffusion data.

A comparison between FP and the F_2 is presented in Figure 4-12 which shows FP and F_2 measured doses plotted vs the value calculated for each point by use of the WIND equation modified for F_2 and HF molecular weights. The calculated-equals-observed line is shown for reference. In terms of ppm-min by volume, the WIND equation for F_2 is

$$\text{ppm-min } F_2 = 9.4\, X^{-1.96}\, \sigma(\theta)^{-0.506}\, (\Delta T+10)^{4.33}\, Q_{F_2}$$

For HF it is

$$\text{ppm - min HF} = 18\, X^{-1.96}\, \sigma(\theta)^{-0.506}\, (\Delta T+10)^{4.33}\, Q_{HF}$$

where

X = Distance to point (feet)

$\sigma(\theta)$ = Standard horizontal deviation in wind direction (deg)

ΔT = Temperature difference between 6 and 56 feet above surface (°F)

Q = Total weight of pollutant released (pounds)

Although distance is not a variable in Figure 4-12, the data fall in distance groupings as shown with the variation in observed data decreasing with distance. (The variation of data close to the source is attributable to terrain effect and is more fully explained in Part 2, Section V.) The 11 fluorine measurements used in this figure were made with the Convair Electrochemical instrument and are all of the fluorine measurements made beyond 1000 feet. Other fluorine measurements were made closer to the source than 1000 feet and with the Tracer lab instrument, but FP measurements could not be made this close because of saturation. In addition, the validity of the WIND diffusion model is not assured for measurements closer than 1000 feet from the source due to inadequate mixing. The most significant observation to be made from this comparison is that resonably good agreement exists between FP dosages that were measured by a conventional, proven technique and the F_2 dosages measured by an experimental instrument under evaluation. This observation validates the feasibility of the fluorine instrument, and what is more important for future planning, validates the prediction of fluorine diffusion by means of an FP simulant. The differences between calculated and observed fluorine

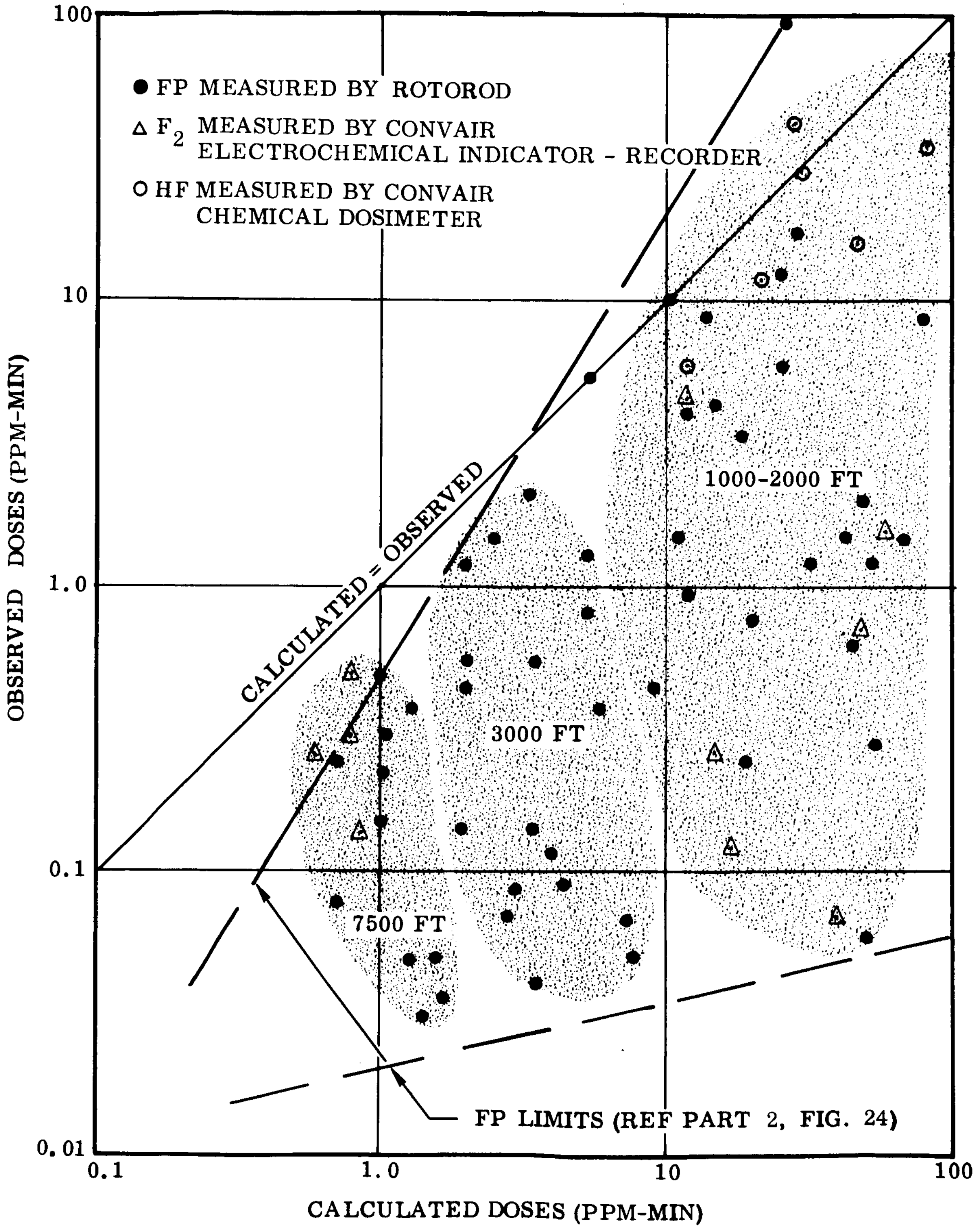


Figure 4-12. Calculated-vs-Observed Values of FP, F_2, and HF

dosages may be qualitatively explained by close examination of the data. However, the acquisition of sufficient data to quantify all variations was beyond the scope of the instrument evaluation. Some of the factors influencing the calculated-vs-observed relationship have been identified as follows:

1. Observed values are not necessarily on the plume center line and, therefore, should be less than calculated by the WIND equation.

2. The response and decay rates of the fluorine recorders tend to make observed readings in the low range (1 ppm-min, which were the values at 7500 feet) higher than actual and, therefore, closer to calculated.

3. In comparison with FP, the assumption must be made that the source is all F_2 and remains F_2 since the rate of conversion beyond 1 minute, or approximately 500 feet, is not known. This inherently makes the observed value of F_2 lower than FP and lower than calculated by the amount of conversion that has taken place during transport to the instrument, since the instrument is sensitive to the F_2 constituent of the sample only.

A quantitative determination of these variables is beyond the scope of this program and relatively unimportant since the gross comparison includes all of the undetermined variables in the process of diffusion, hydrolysis, and instrument characteristics.

A similar comparison of the other three instruments with FP is impossible from the data available. This arises from the fact that the mix of instrumentation for evaluation was selected or adjusted to provide a range of sensitivities from the order of 1 ppm to in excess of 500 ppm. This required that the more sensitive instruments be deployed further from the source (500 to 1000 feet minimum) which is inside the limit of the FP data. The less sensitive or higher range instruments were deployed closer to the source. An examination of this data leads to a qualitative evaluation, but because of various operational failures discussed previously and summarized in Table 4-3, no quantitative evaluation can be made.

For fluorine measurement, the Convair Electrochemical indicator-recorder is satisfactory in its present form for the measurement of fluorine peak concentration and dosage over a wide range of values. The accuracy, reliability, operational life, simplicity of operation and servicing are all well within the requirements of an instrument for toxic-gas monitoring. The Tracerlab indicator recorder is a potentially satisfactory instrument for this purpose but will require extension of clathrate life, desensitization to humidity, and improved battery life to provide acceptable and reliable service. In addition, the high-range cutoff device should be deleted.

For hydrogen fluoride, the Convair chemical dosimeter, coupled with the analytical procedure described elsewhere in this section, is suitable for dosages of 100 ppm-min or more of HF as well as 40 ppm-min or more of F_2. Other analytical procedures are available that might improve the sensitivity but no attempt was made to evaluate other procedures. The Davis Electroconductivity instrument, which is nominally a hydrogen-fluoride sensor, is least suitable because of its inherent cross-sensitivity to any ionizing gas. In addition, it is too heavy for a portable instrument, the battery life is too short for most applications, and the adjustment of flow prior to operation is uncertain and unreliable.

V. TEST OPERATIONS

The test program consisted of 31 tests conducted at Sycamore Canyon (S-2 site) between April and October of 1965. There were three principal categories of tests: Tracer Diffusion Tests, Cold Source Tests, and Hot Source Tests.

Seven releases of fluorescent particle (FP) tracer material were made at the S-2 site before oxidizer spills were conducted. These tests were made to evaluate the natural diffusion characteristics of the Sycamore test area under various atmospheric conditions prior to the release of toxic products. Three additional releases of FP alone were made later in the program to supplement the initial data and to compare two types of disseminators.

Nine cryogenic evaporation and diffusion tests were made in addition to a system checkout test. Five of the Cold Source Tests were made with LO_2 and four with a 30 percent LF_2/70 percent LO_2 mixture. Evaporation rates were first determined for four containment basin configurations with LO_2. Various quantities of LF_2/LO_2 were then evaporated from one selected basin in the final four tests to provide a cold source of fluorine products. A water fog was evaluated as a fluorine suppressant in the last two tests. Smoke was released during the LO_2 tests to aid in determining the downwind path of the products of evaporation, and tracer material was released during all but the last two LF_2/LO_2 tests. Downwind concentrations of fluorine and hydrogen fluoride were measured in addition to FP during the LF_2/LO_2 evaporation.

Eleven diffusion tests were conducted in which an instantaneous hot cloud was produced by spilling LF_2/LO_2 on charcoal or RP-1 fuel. Tracer material was released into the hot cloud during ten of these tests; for the last eight tests, an additional release of a different-colored FP was made about 10 minutes after the rise of the hot cloud to obtain data for a cold source and hot source comparison. A list of the individual tests and supporting operations is presented in Tables 5-1 through 5-3.

Because of the pollutional characteristics of fluorine, these tests were conducted within the limits of a NASA Citation Permit and Site Approval. In the following paragraphs the text of this citation is reproduced and each test category is discussed in detail. Test objectives, procedures, and data reduction techniques are described, and the test results are analyzed.

A. Citation Permit and Site Approval

The Citation Permit and Site Approval was received on May 10, 1965 prior to commencement of test operations. The text of the Citation Permit is as follows:

Citation Permit and Site Approval is hereby granted subject to the following conditions and operating limitations for use of S-2 facility for FLOX tests:

a. Convair shall inform the local pollution control authorities (State, County and/or Municipal Control Board for Air, Soil and Water Pollution), concerned with Sycamore Canyon S-2 FLOX testing, of the nature add extent of the FLOX Program in order to obtain their concurrence in the operational restrictions for pollution control.

b. Pollution sampling and detection instrumentation shall be provided to record, document and maintain records of peak concentrations and total quantities (as a function of time) of the pollutant passing the boundaries of Sycamore Canyon.

1. Emergency exposure of operational personnel to F_2 and HF concentrations within Sycamore S-2 Facility exclusion area (that area closed to non-operational personnel during testing) shall not exceed the Emergency Tolerance Limits (ETL) as follows:

TIME	HF CONCENTRATION
5 Minutes	30 ppm
15 Minutes	20 ppm
30 Minutes	10 ppm
60 Minutes	8 ppm

TIME	F_2 CONCENTRATION
5 Minutes	5 ppm
15 Minutes	3 ppm
30 Minutes	2 ppm
60 Minutes	1 ppm

2. Exposure to personnel within the Sycamore Canyon Boundary (Government Property Boundary) shall not exceed Threshold Limits Values (TLV) of 3 ppm HF/8 hour day (equivalent to 1440 ppm minutes) or 0.5 ppm F_2/8 hour day (equivalent to 240 ppm minutes).

3. F_2 and HF Pollutant Concentration at ground level, including any ground supported structure outside the Sycamore Canyon Facility, shall not exceed the following limits.

   a) Hydrogen Fluoride:

      1) Peak concentration not to exceed 5 ppm for 10 minutes (equivalent to 50 ppm minutes).

      2) Time weighted average concentration not to exceed 0.03 ppm/14 days (equivalent to 604.8 ppm minutes).

   b) Elemental Fluoride

      1) Peak concentration not to exceed 0.5 ppm for 10 minutes (equivalent to 5 ppm minutes).

      2) Time weighted average concentration not to exceed 0.01 ppm/14 days (equivalent to 201.6 ppm minutes).

4. All tests involving the release of F_2 and HF shall be conducted during appropriate meteorological conditions in a manner acceptable to the Contracting Officer that would prevent downwind drift of the pollutant into populated areas.

   a) Record, document, and maintain records of meteorological conditions.

   b) Caution shall be exercised to prevent exposure of humans and animals to F_2 and HF outside the exclusion area.

   c) All testing shall be performed to preclude the possibility of irreparable damage to valuable plant life.

c. Soil and water sampling and analysis for fluoride shall be required to document possible pollution in a manner acceptable to the Contracting Officer and shall include but not be limited to the following:

   1. Before FLOX testing, measurements and records of 'Normal Background' fluoride content of the soil and water of the area that may be affected.

   2. After FLOX testing, measurements and records of the soil and water for fluoride content for pollution of the area that may be affected.

Paragraph "a" of the Citation Permit was complied with by discussing the proposed test program with the San Diego Department of Public Health and the San Diego Water Pollution Control Board, and then requesting their approval. Formal concurrence of these authorities was obtained and is on file. (References 1, 2, and 3)

Paragraph "b" of the Citation Permit was complied with as follows:

Boundaries of Sycamore Canyon: As shown in Figure 3-10, the test site boundary in the downwind area or eastward from site S-2 is approximately 2 miles to the east and south, and 1 mile to the north. This boundary represents the extremities of government property designated as Sycamore Test Site. Although this area is posted, it is only partially fenced and is readily accessible to the public by foot and vehicle. Normally, no attempt is made to exclude trespassers, but during these tests the area was under surveillance by aircraft and field parties.

Within the test site boundary is a security fence to exclude the public from active test areas. This fence is also shown in Figure 3-10. For purposes of citation compliance, the security fence was considered to be the "boundary of Sycamore Canyon" during these tests. For larger-scale activities, it might be desirable, if not mandatory, to install a security fence at the actual site boundary to extend the exclusion area.

Fluorine and fluoride sensors were positioned within the security fence for all tests involving the release of fluorine. For some tests, sensors were placed outside the security-fenced area to a distance of approximately 5 miles.

In no instance did the peak concentration dosage of F_2 or of HF exceed the limit established by paragraphs "b-1, b-2, and b-3" of the Citation Permit.

Table 5-1. Chronological Test Operations Summary

DATE (1965)	TEST NO.	EVENT
27 May	1	Conducted first fluorescent particle natural tracer diffusion trial (MRI)
28 May	2-5	Conducted second through fourth fluorescent particle natural tracer diffusion trial (MRI)
29 May	6-7	Conducted fifth and sixth fluorescent particle natural tracer diffusion trial (MRI)
2 June		Completed test site, leak and functional checkout
4 June		Completed FLOX system passivation
7 June		Transferred LO_2 to FLOX storage tank
8 June	8	Conducted non-combustive LOX spill for system checkout
9 June	9	Resupplied LO_2 to FLOX storage tank, conducted first non-combustive LOX spill test
10 June		Resupplied LO_2 to FLOX storage tank
11 June	10	Conducted second non-combustive LOX spill test
14 June	11	Resupplied LO_2 to FLOX storage tank, conducted third non-combustive LOX spill test
15 June		Resupplied LO_2 to FLOX storage tank, fourth non-combustive LOX spill test canceled due to weather
16 June		Canceled fourth non-combustive LOX spill test due to weather
17 June	12	Conducted fourth non-combustive LOX spill test
22 June		Transferred LO_2 and LF_2 to FLOX storage tank
23 June		Canceled first non-combustive FLOX spill test due to weather
24 June	13-14	Conducted first and second non-combustive FLOX spill tests
25 June	15	Canceled third non-combustive FLOX spill test due to weather, conducted fluorescent particle natural tracer diffusion trial (MRI)
28 June	16	Conducted third non-combustive FLOX spill test
29 June	17	Conducted fourth non-combustive FLOX spill test
1 July		Transferred LO_2 and LF_2 to FLOX storage tank
6 July	18	Conducted first combustive FLOX spill test
8 July	19	Conducted second combustive FLOX spill test
10 July		Transferred LO_2 and LF_2 to FLOX storage tank
12 July	20	Conducted third combustive FLOX spill test
13 July		Transferred LO_2 and LF_2 to FLOX storage tank
19 July	21	Conducted fourth combustive FLOX spill test
21 July	22	Conducted fifth combustive FLOX spill test
23 July		Transferred LO_2 and LF_2 to FLOX storage tank

Table 5-1. Chronological Test Operations Summary (Cont)

DATE (1965)	TEST NO.	EVENT
27 July	23	Conducted sixth combustive FLOX spill test
30 July	24	Conducted seventh combustive FLOX spill test
2 August		Canceled FLOX storage tank resupply due to leak in LOX transfer facility
3 August		Transferred LO_2 and LF_2 to FLOX storage tank
4 August	25	Conducted eighth combustive FLOX spill test
6 August		Transferred LO_2 and LF_2 to FLOX storage tank
9 August	26	Conducted ninth combustive FLOX spill test
11 August		Transferred LO_2 and LF_2 to FLOX storage tank
12 August		Canceled tenth combustive FLOX spill test due to weather
13 August		Canceled tenth combustive FLOX spill test due to weather
31 August	27	Conducted tenth combustive FLOX spill test
1 Sept		Canceled FLOX storage tank resupply due to leak in LOX transfer facility
2 Sept		Transferred LO_2 and LF_2 to FLOX storage tank
3 Sept	28	Conducted eleventh combustive FLOX spill test
3 Sept	29	Conducted fluorescent particle natural diffusion trial (MRI)
28 Sept	30	Conducted reference test on blast instrumentation by firing shaped charge on empty tank
12 Oct	31	Conducted reference test on fluorescent particle disseminators by using two-color FP releases from two separate disseminators (MRI)

Table 5-2. Test Summary

TEST NO.	SOW* TEST	MRI TEST NO.	DATE (1965)	TEST DESCRIPTION	FUEL QUANTITIES (lb.) RP-1	CHARCOAL PLACED	CHARCOAL REMAINING	CHARCOAL CONSUMED	OXIDIZER (lb) LOX	OXIDIZER (lb) FLOX	SAMPLE FLOX (%)	LF_2 IN SPILL (lb)	BASIN SIZE (ft)	REMARKS
1		GD-1	27 May	FP Natural Diffusion Trial										
2		GD-2	28 May	FP Natural Diffusion Trial										Performed by MRI. Results reported in Part 2
3		GD-3	28 May	FP Natural Diffusion Trial										
4		GD-4	28 May	FP Natural Diffusion Trial										
5		GD-5	28 May	FP Natural Diffusion Trial										
6		GD-6	29 May	FP Natural Diffusion Trial										
7		GD-7	29 May	FP Natural Diffusion Trial										
8		GD-8	8 June	Non-combustive LOX Checkout					1360				5x5x2-1/2	
9	1	GD-9	9 June	First Non-combustive LOX Spill					3420				5x5x2-1/2	
10	2	GD-10	11 June	Second Non-combustive LOX Spill					3360				4x4x4	LOX Evaporation Test
11	3	GD-11	14 June	Third Non-combustive LOX Spill					3130				2-1/2x2-1/2x10	
12	4	GD-12	17 June	Fourth Non-combustive LOX Spill					3190				8x8x1	
13	5	GD-13	24 June	First Non-combustive FLOX Spill						870	32.5	282.0	4x4x4	FLOX Evaporation Test
14	6	GD-14	24 June	Second Non-combustive FLOX Spill						560	32.5	182.0	4x4x4	
15		GD-15	25 June	FP Natural Diffusion Trial										Performed by MRI. See Part 2
16	7		28 June	Third Non-combustive FLOX Spill						540	32.5	175.0	4x4x4	FLOX Evaporation Test
17			29 June	Fourth Non-combustive FLOX Spill						630	32.5	204.0	4x4x4	
18	8		6 July	First Combustive FLOX Spill		50	NR†	NR		100	32.5	32.5	8x8x1	After Fire Deluged
19	15	GD-16	8 July	Second Combustive FLOX Spill		175	NR	NR		500	32.5	162.5	8x8x1	After Fire Deluged
20	16	GD-17	12 July	Third Combustive FLOX Spill		660	513	147		2000	32.2	644.0	8x8x1	Poor reaction. No fireball
21	17	GD-18	19 July	Fourth Combustive FLOX Spill		800	NR	NR		2000	33.5	670.0	8x8x1	Poor reaction. No fireball
22	9	GD-19	21 July	Fifth Combustive FLOX Spill	208					500	33.5	167.5	8x8x1	Good fireball, low cloud persistence
23	10	GD-20	27 July	Sixth Combustive FLOX Spill	250					1000	29.7	297.0	8x8x1	Good fireball, low cloud persistence
24	11	GD-21	30 July	Seventh Combustive FLOX Spill		1250	930	320		2500	29.7	742.5	27 ft-8 in.	1 ft-4 in. High block retaining wall
25	12	GD-23	4 Aug	Eighth Combustive FLOX Spill		1500	1255	245		3000	30.2	906.0	27 ft-8 in.	2 ft-8 in. High block retaining wall
26	13	GD-24	9 Aug	Ninth Combustive FLOX Spill		1500	1286	214		3000	29.4	882.0	27 ft-8 in.	2 ft-8 in. High block retaining wall
27	14	GD-25	31 Aug	Tenth Combustive FLOX Spill		1500	1390	110		3000	29.2	876.0	27 ft-8 in.	2 ft-8 in. High block retaining wall
28	18	GD-26	3 Sept	Eleventh Combustive FLOX Spill		1500	1366	134		3000	32.1	963.0	27 ft-8 in.	2 ft-8 in. High block retaining wall
29		GD-27	3 Sept	FP Natural Diffusion Trial										Two tests: One with wall, One without wall. FP Release from continuous and instantaneous disseminators.
30			28 Sept	Shaped Charge Test										
31			12 Oct	FP Natural Diffusion Trial										

†NR Quantities not recorded
*SOW Contract Statement of Work (See Table 5-3)

Table 5-3. Contract Statement of Work Spill Test Matrix

SOW NO. TEST	ITEM	MATERIAL	OXIDIZER (lb)	BASIN (ft)	WIND DIRECT	LAPSE RATE	DECONTAMINATE AGENT
1	1	LOX	2,870	8x8x1	Primary	Unstable	None
2	1	LOX	2,870	5x5x2-1/2	Primary	Stable	None
3	1	LOX	2,870	4x4x4	Primary	Unstable	None
4	1	LOX	2,870	2-1/2 x 2-1/2x10	Primary	Stable	None
5	1	30% FLOX	3,080	4x4x4	Primary	Unstable	None
6	1	30% FLOX	3,080	4x4x4	Primary	Unstable	FOG
7	1	30% FLOX	3,080	4x4x4	Primary	Unstable	FOG
8	2	30% FLOX RP-1	100	8x8x1	Primary	Unstable	None
9	2	30% FLOX RP-1	500	8x8x1	Primary	Stable	None
10	2	30% FLOX RP-1	3,000	8x8x1	Primary	Unstable	None
11	2	30% FLOX RP-1	3,000	8x8x1	Primary	Stable	None
12	2	30% FLOX RP-1	3,000	8x8x1	Primary	Stable	None
13	2	30% FLOX Charcoal	500	8x8x1	Primary	Unstable	None
14	2	30% FLOX Charcoal	3,000	8x8x1	Primary	Stable	None
15	2	30% FLOX Charcoal	3,000	8x8x1	Primary	Stable	None
16	2	30% FLOX Charcoal	3,000	8x8x1	Primary	Unstable	None
17	. . . . Undesignated backup						
18	. . . . Undesignated backup						

Paragraph "b-4" compliance is fully documented in Section V of this report, which shows the operational considerations for each test and the meteorological conditions that prevailed. No report of human, animal, or plant exposure to fluorine was received.

Site S-2 personnel conducting the test program were all positioned in the blockhouse area approximately 500 ft upwind from the release point. Fill and mix operations preceding tests were conducted in accordance with established procedures for fluorine handling. Technicians working in pairs were suited in protective clothing with self-contained breathing devices. Emergency personnel and equipment were onsite during all operations. With the exception of infrequent trace odors of fluorine, no exposures were experienced by test personnel during this program. Although foliage within a distance of 200 ft downwind from the test pad discolored in a random pattern, beyond 200 ft there was no noticeable effect on vegetation.

Site S-4, located 2000 ft NNE from the test pad, was active during this program and was occupied by up to 60 people. S-4 personnel were alerted immediately prior to fluorine release, but no other special precautions were taken. Several trace to strong odors of fluorine were reported by S-4 personnel, but no work interruption was experienced.

An observer positioned on the north-south highway 5 miles east of the release point at the Gravel Pit and "Y" point reported trace odors of fluorine on tests 20, 21, and 25. These observations were intermittent for a few seconds over a 10-minute period. The intensity was very small and probably would not have been noticed by an inexperienced observer. The observations were supplemented by fluoride measurements taken in the same area. That all readings were of HF rather than F_2 is evidence that F_2 hydrolizes to the less toxic HF in the presence of atmospheric moisture. The odors of the two gases are not easily distinguished from one another.

B. Tracer Diffusion Tests

The initial series of tracer releases was made to establish the natural diffusion characteristics of the Sycamore test area in the absence of any possible effect of hot or cold clouds of oxidizer and fuel products. These tests were followed by release of FP both during the non-combustive and combustive spills for correlation with downwind measurements of fluorine and hydrogen fluoride.

The tracer diffusion tests were conducted by Meteorology Research, Inc. (MRI). Test results prepared by MRI are reported in detail in Part 2 of this report. The data obtained in this program was evaluated by MRI in conjunction with results from the numerous field diffusion studies previously carried out under a variety of geographical and environmental conditions. The use of this existing background of data has permitted the diffusion capabilities of the Sycamore test area to be defined with a minimum number of tests.

C. Cold Source Tests

The Cold Source Tests were designed to simulate a spill of LF_2/LO_2 in the absence of fuel, such as would occur in the event of a storage tank or line rupture. Since an uncontained spill of large quantities of LF_2/LO_2 onto open ground would result in an almost instantaneous boiloff of the cryogenic, with prohibitive downwind concentrations of toxic material, containment basins must be provided for spillage from storage tanks and transfer lines. The Cold Source Tests provided evaporation rates from containment basins and the optimum configuration for such basins.

Five tests were conducted with LO_2 which was used in lieu of the LF_2/LO_2 mixture in order to minimize the required safety precautions and expedite the initial tests. The similarity of the boiling points of LF_2 and LO_2 (-297°F vs -306°F) is adequate to give an accurate simulation of the evaporation characteristics. A nominal LO_2 quantity of 3000 lb was used for each test with the exception of the first checkout operation. Four containment basins varying from a shallow 8 x 8 x 1 ft basin to a deep basin measuring 2-1/2 x 2-1/2 x 10 ft were tested. Table 5-2 shows the configuration for each test. The use of a fixed quantity of cryogenic provided a ready means of determining the effect of basin geometry on evaporation rate.

In addition to obtaining evaporation data, the effect of large-scale cryogenic evaporation on the diffusion characteristics of the site was studied. FP tracer material was released into the evaporation cloud and sampled at several crosswind lines at distances to 1.5 miles downwind from the release point. This provided data for comparison with the previous tests in which no cryogenic was evaporated. Smoke was also released during the evaporation, and the path of the smoke plume was photographed to provide a visual check on the movement of the products of evaporation. Camera coverage was provided by two still cameras as shown in Figure 5-1.

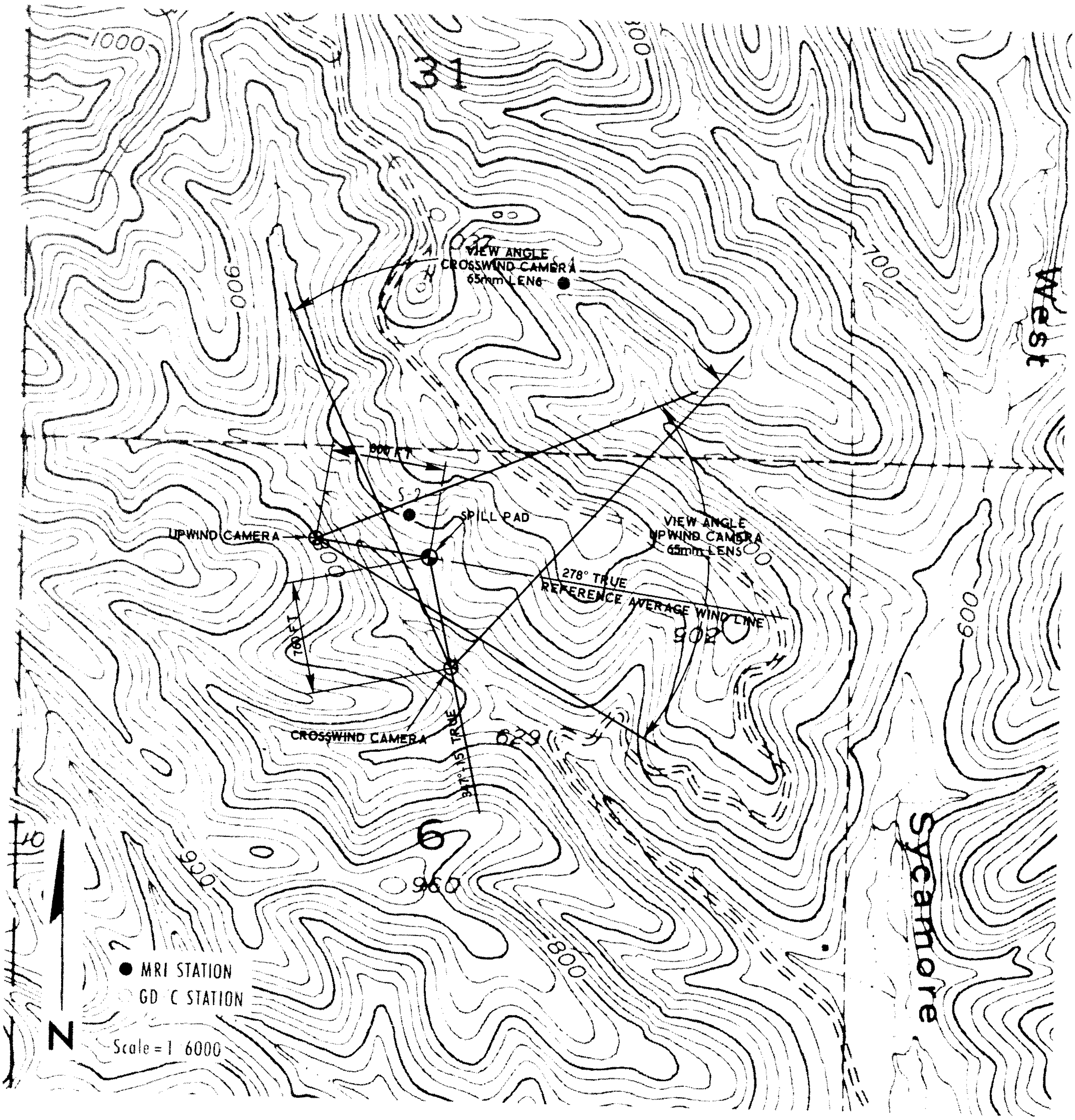


Figure 5-1. Still Camera Locations

The final series of four tests was conducted with quantities of from 540 to 870 lb of a 30 percent LF_2/70 percent LO_2 mixture using the 4 x 4 x 4 ft containment basin. The smaller quantities and the single basin were used for these tests since the objective was limited to providing a source of fluorine products for diffusion study and detection evaluation. The downwind concentrations of fluorine and hydrogen fluoride were measured during these tests, and FP tracer particles were released and the concentrations measured for correlation with the fluorine and hydrogen fluoride. No smoke was released because of the possibility of contaminating and invalidating the fluorine and hydrogen fluoride detector measurements.

A water fog was employed in the last two tests in the LF_2/LO_2 series to determine the effectiveness of water in suppressing the downwind fluorine concentrations. The water was sprayed over the 4 x 4 x 4 ft basin using a single Spraying Systems Co. 2H60 nozzle, which produced a fine spray of 1000-2000 micron water droplet size at 35 gpm and 40 psig. The vaporized fluorine passed through the fog and was partially hydrolized to hydrogen fluoride.

Approximately half of the cryogenic in each test was allowed to evaporate before the water spray was turned on. This permitted a comparison of downwind fluorine concentrations during two controlled periods to determine the effect of the water spray.

1. Test Objectives

The specific objectives of the Cold Source Tests were as follows:

a. Determine evaporation rates of the cryogenic from typical containment basins.

b. Determine optimum geometry of containment basin for minimum evaporation rate.

c. Determine possible effect of the cold plume from a cryogenic boiloff on natural diffusion.

d. Correlate tracer diffusion results with simultaneous downwind measurements of fluorine and hydrogen fluoride concentrations.

e. Correlate visual smoke trajectory with tracer and fluorine diffusion results.

f. Evaluate the effectiveness of water fog in controlling and suppressing the downwind concentration of fluorine from a non-combustive spill of LF_2/LO_2.

2. Test Procedure

Non-Combustive Lox Spill Test Procedure 00514 (Appendix V) and Flox Cold Spill Test Procedure 00523 (Appendix VI) were followed to transfer LO_2 and LF_2/LO_2 mixture into the containment basins for tests 8 through 17.

To correlate evaporation rate and synchronize tracer diffusion data, a "characteristics time" was established for paragraph 3.0, steps 29, 30, 31, and 32, of the 00514 procedure. The basin was filled to slightly over the top sensor to assure a minimum quantity in the basin. Flow was then terminated and evaporation allowed to proceed until the top sensor was uncovered as indicated by a sharp rise in temperature. This point was defined as the "characteristic time."

The quantity transferred from the supply during the filling operation was determined by measuring the total quantity remaining in the supply tank. The rate of evaporation from the basin was established by recording the total quantity remaining in the basin as a function of elapsed time, the quantity being indicated by the uncovering of the sensors.

The tracer material and smoke were released at the beginning of the evaporation at the characteristic time. Both the tracer material and the smoke were released from a position near the basin where they would mix with the cloud of evaporating cryogenic. The release of tracer material and smoke was continued for approximately 10 minutes. During this period, still pictures were taken of the smoke plume at regular intervals.

Sampling of the tracer material and measurements of fluorine and hydrogen fluoride were made at a network of stations downwind from the release point. The tracer sampling was carried out by MRI. The locations of the MRI stations are shown in Figure 1 of Part 2. The sampling stations for the fluorine and hydrogen fluoride as used in each test are shown in Figures 5-61 through 5-64. Since a limited number of instruments were available, they were relocated for each test in the anticipated path of the evaporation plume as indicated by the prevailing wind direction prior to the start of the test.

Seventeen instruments were used. Fluorine was measured by six Convair instruments (K-1 through K-6) and three Tracerlab instruments (T-1 through T-3); hydrogen fluoride was measured by four Davis instruments

(D1 through D4); and combined dosage of fluorine and hydrogen fluoride was measured by four Convair instruments (R-1 through R-4).

3. Results

Results of the cold source test are discussed under three headings: Evaporation, Smoke Observation, and Fluorine and Hydrogen Fluoride Concentration.

a. Evaporation

The LO_2 evaporation data for the four containment basins is shown in Figures 5-2 and 5-3. Figure 5-2 shows the total LO_2 evaporated versus time after the beginning of liquid flow from the supply line. Three distinct periods are shown. In the first, the bottom of the basin is being chilled down. The evaporation rate during this chilldown period is equal to the LO_2 supply rate and approximates the high evaporation rate that would be experienced in an uncontained spill. The total weight evaporated during this period is the quantity required for the initial chilldown of the bottom of the basin.

In the second period, during which the liquid level is rising in the basin, the evaporation rate is low and, in some tests, almost negligible. The low rate results from the more gradual contact of unchilled surface area as the liquid level rises and the retarding effect of the sensible heat capacity of the subcooled liquid. In some cases, it appears that all the heat absorbed from the walls of the pit goes into raising the temperature of the liquid, with no evaporation occurring.

During the third period, after the basin is filled and the bulk temperature of the cryogenic has reached the boiling temperature, the curve indicates a gradually decreasing evaporation rate. Figure 5-3, showing the evaporation rate following the filling of the basin, indicates a rapid initial decrease and then a gradual levelling out to a low rate; several hours is required for evaporation of the total quantity. This data illustrates that evaporation rate can be controlled by containing the spill in an open basin; by contrast, almost instantaneous evaporation takes place without containment.

The basins used in these tests had approximately the same volume, and approximately the same quantity of LO_2 was pumped into each. The wetted area of the basin and the surface area of the liquid varied. The effect of surface area on evaporation rate is negligible in these tests, since the heat transfer from the air is small compared with that from the concrete surface of the basin. The evaporation rate for a given volume of cryogenic is almost solely a function of

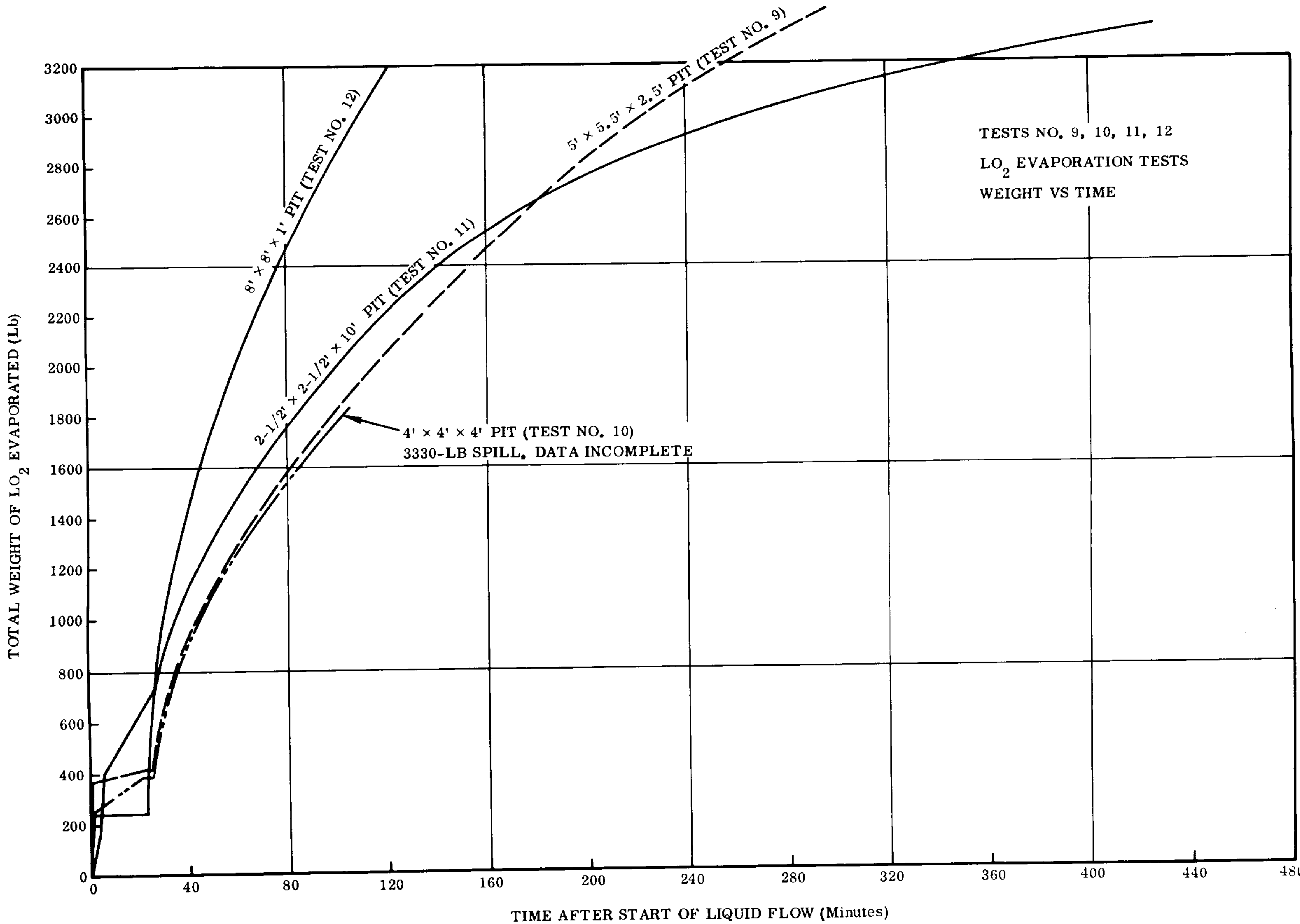


Figure 5-2. Weight of LO_2 Evaporated

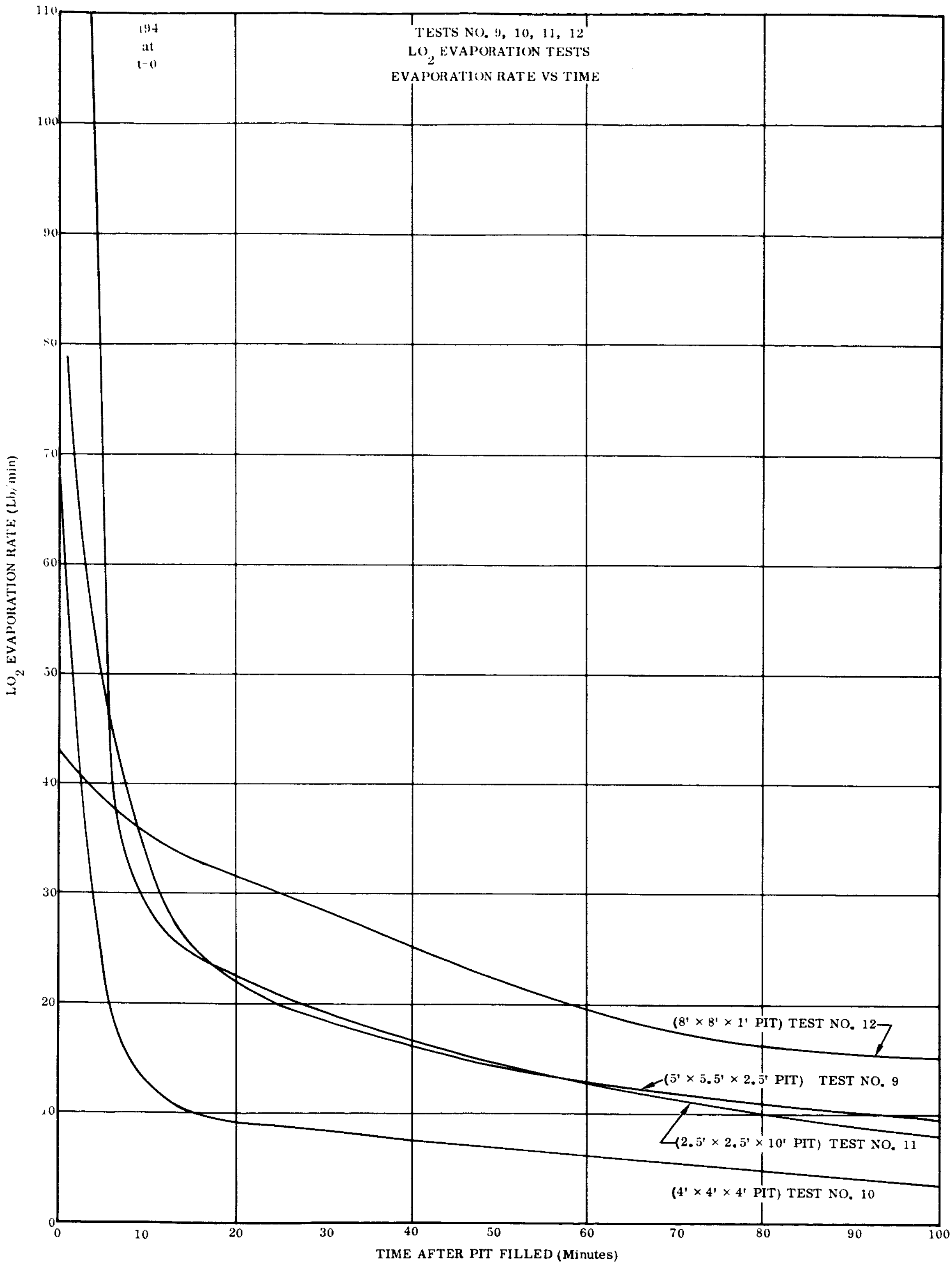


Figure 5-3. LO_2 Evaporation Rate

the heat transfer from the walls of the basin. The evaporation characteristics shown in Figures 5-2 and 5-3 bear this out. The deepest basin (2-1/2 × 2-1/2 × 10 ft) had the greatest wetted area and, because of its small bottom area, evaporated the smallest quantity of LO_2 during fill. It had the highest heat transfer rate from the wall and the highest evaporation rate immediately after fill. Conversely, as the liquid level falls, the wetted area and thus the evaporation rate drop off more rapidly than with the other basins. The shallowest basin (8 × 8 × 1 ft), on the other hand, evaporates the greatest quantity of LO_2 during childown, and has the smallest change in wetted area with change in liquid level. Consequently, it shows the lowest evaporation rate immediately after fill and the lowest change in rate with time. The lowest average evaporation rate was achieved with the 4 × 4 × 4-ft basin because this configuration had the minimum heat transfer surface for a given volume of cryogenic.

The cryogenic evaporation had no apparent effect on the diffusion characteristics of the test area. The low evaporation rates of the cryogenic from the basins cause the vapor to warm quickly to ambient temperature and there is no significant alteration in the subsequent motion or diffusion pattern of the cloud.

The evaporation data for the tests with LF_2/LO_2 are shown in Figures 5-4 through 5-6. The two liquids evaporate at different rates, resulting in a mixture of varying composition. Figure 5-5 shows the evaporation rate for the mixture and Figure 5-6 shows it for the LF_2.

The data for the last two tests (tests 16 and 17) indicate an early termination of the evaporation. The water fog used at this point to test its effectiveness in suppressing downwind concentrations of fluorine products resulted in a reaction that completely evaporated the remaining liquid in the pit within a few seconds.

b. Fluorine and Hydrogen Fluoride Concentrations

The data for the cold source measurements of fluorine and hydrogen fluoride is presented in Figures 5-61 through 5-64. The total dosage and peak concentrations are tabulated for each station used for each test. The corresponding station location is shown on a map of the test area, and the mean wind velocity and direction at the spill site are indicated.

Typical time plots of the downwind fluorine concentrations measured during test 16, in which water fog was used, are shown in Figures 5-11 and 5-12 for comparison with data from tests 13 and 14 (Figures 5-13 and 5-14), in which no spray was used. It is difficult to make a station-by-station comparison of the dosages since the instruments were relocated from one test to another. The effect of the water spray is best indicated by the change in the concentration patterns following initiation of the water spray. It is noted in test 16 that a number of concentration peaks of varying intensity are recorded prior to the time the spray was turned on; after the spray was turned on, there was either no further trace of fluorine or only a single peak.

In contrast, tests 13 and 14 show the typical pattern to be one of recurring peak concentration both before and after a corresponding point in time. Although this represents very meager data for evaluation, the comparison does indicate that the water spray was effective in reducing the downwind dosage. It further indicates that the water spray may be an effective means of limiting the downwind exposure to a short period of time following initiation of the water spray. Where a peak concentration followed immediately after the water spray, the peak did not tend to be higher than preceding peaks resulting from the normal evaporation. This indicates that a major portion of the large quantity of fluorine that flashed off as a result of the water spray may have been converted to an aqueous solution of hydrogen fluoride that was not carried out far enough to be measured at any of the instrument stations.

c. Smoke and FP Observations

Figure 5-7 is a photograph of a typical plume from the smoke released during the LO_2 evaporation tests. The path traced out by the leading edge of the smoke plume was determined from scaled measurements of the pictures taken from the two ground cameras. Sketches of the smoke plumes for tests 10, 11, and 12 are presented in Figures 5-8 through 5-10. Data from aircraft observations are presented in Part 2. The FP data in Part 2 shows good correlation with the smoke plume, the maximum concentrations being measured in the observed path of the plume.

D. Hot Source Tests

The Hot Source Tests were designed to simulate a catastrophic spill of LF_2/LO_2 in the presence of fuel. An example of this condition would be tank rupture after dual propellant loading. Various quantities of LF_2/LO_2 were dropped on charcoal or RP-1 fuel. The tests were conducted with small-scale spills until evaluation of toxic hazards to the nearby populated area was completed. Initial tests were run with 100 lb of oxidizer; the quantity was gradually increased until the later tests were run with 3000 lb.

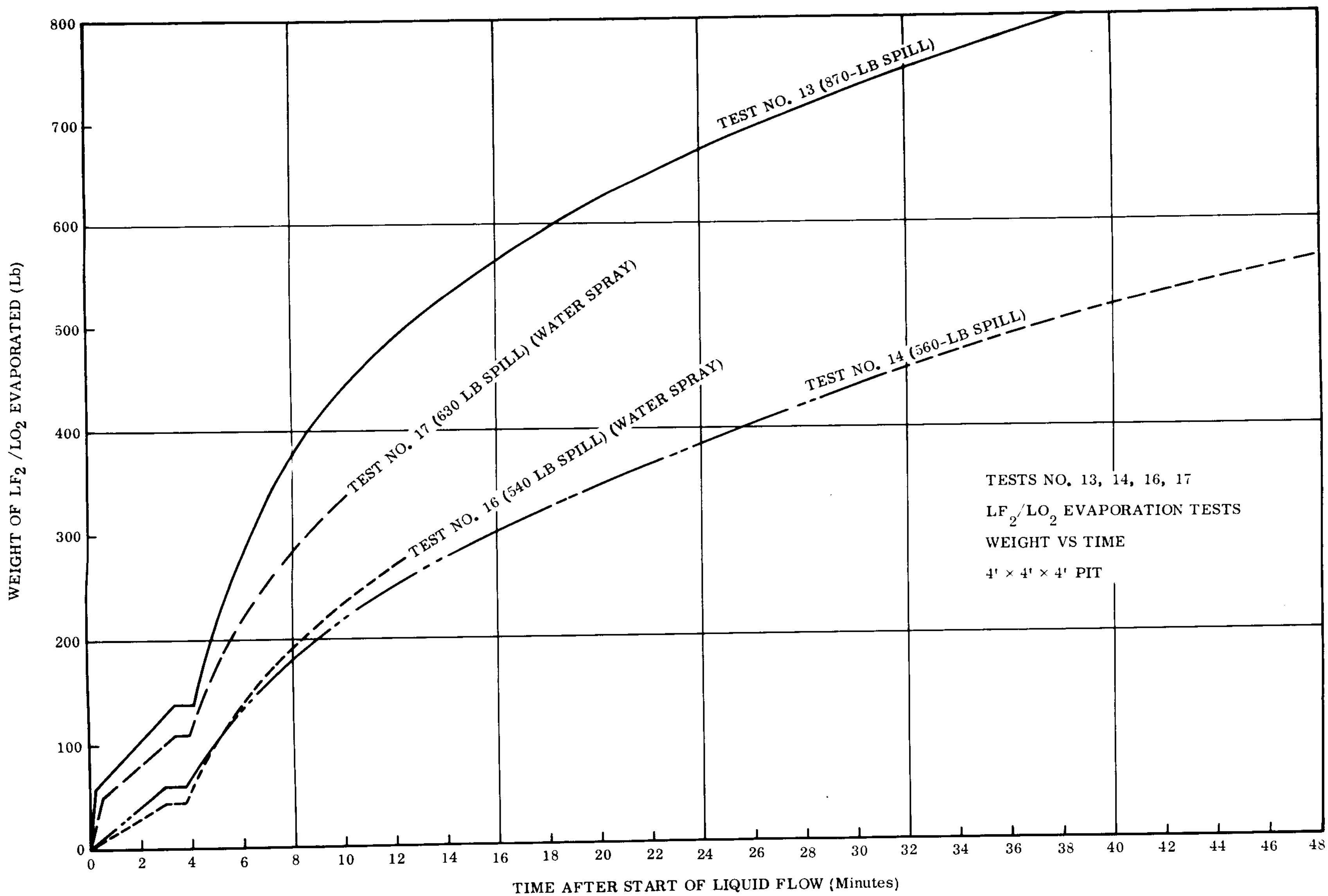


Figure 5-4. Weight of LF_2/LO_2 Evaporated

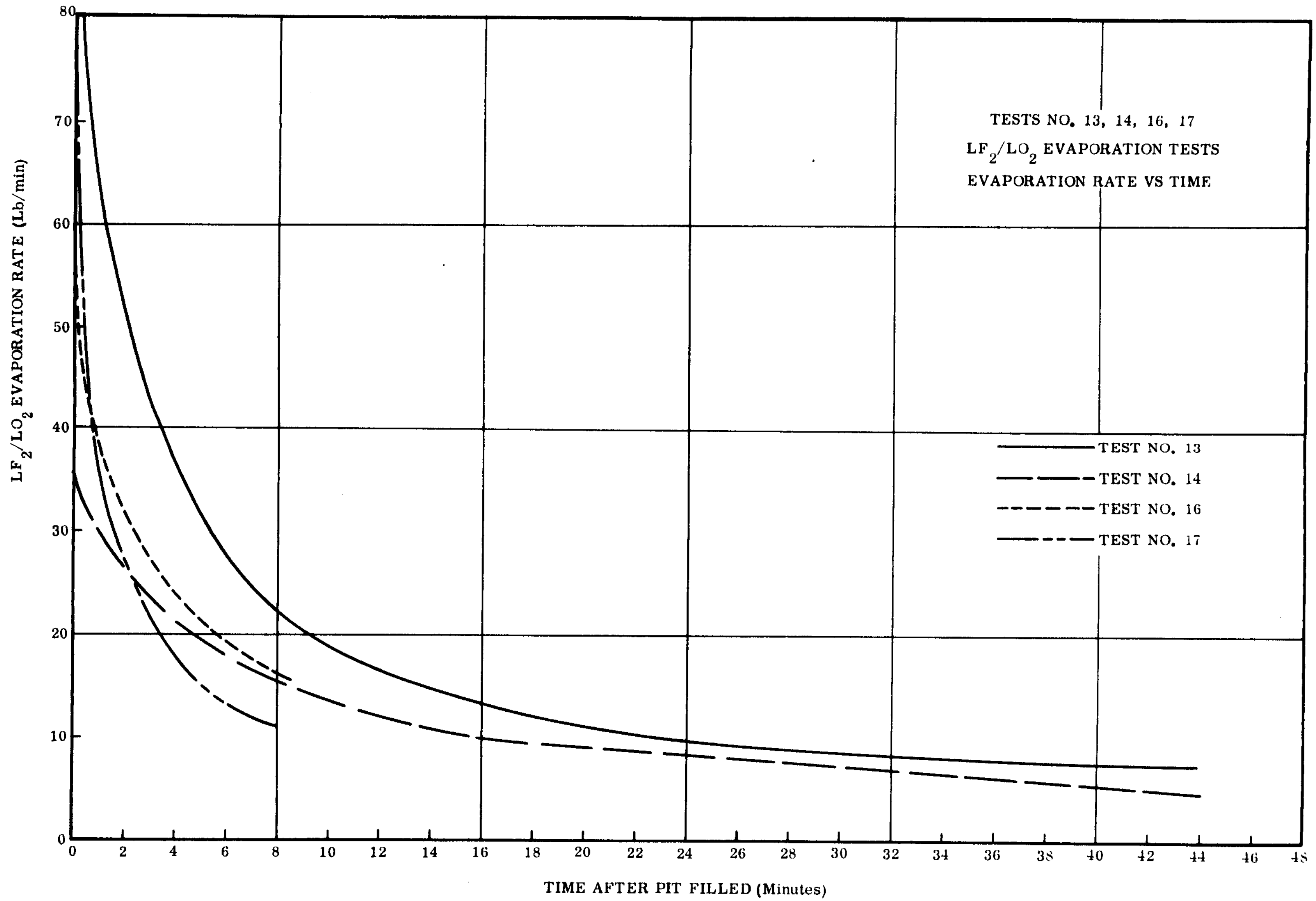


Figure 5-5. LF_2/LO_2 Evaporation Rate

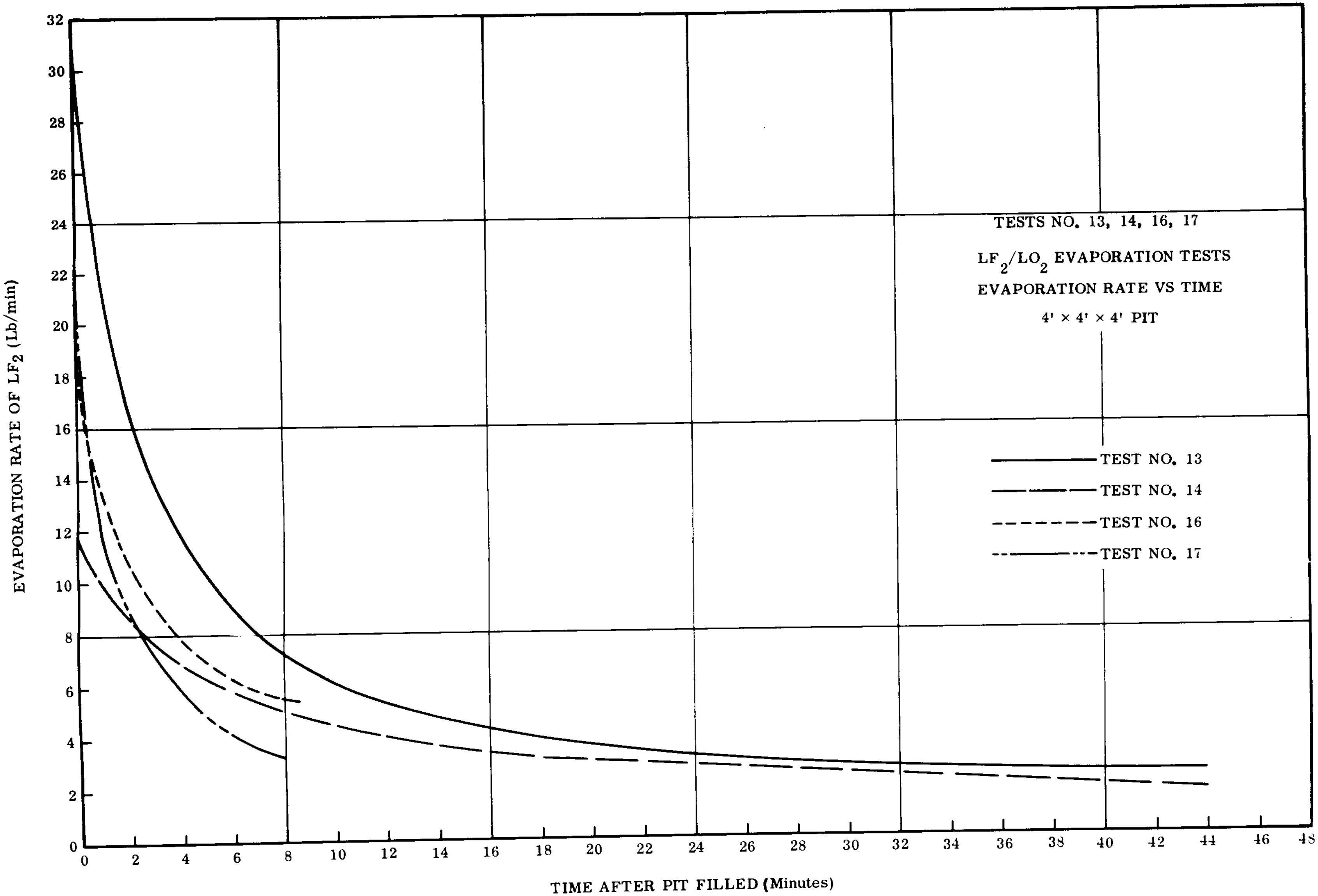


Figure 5-6. LF_2 Evaporation Rate

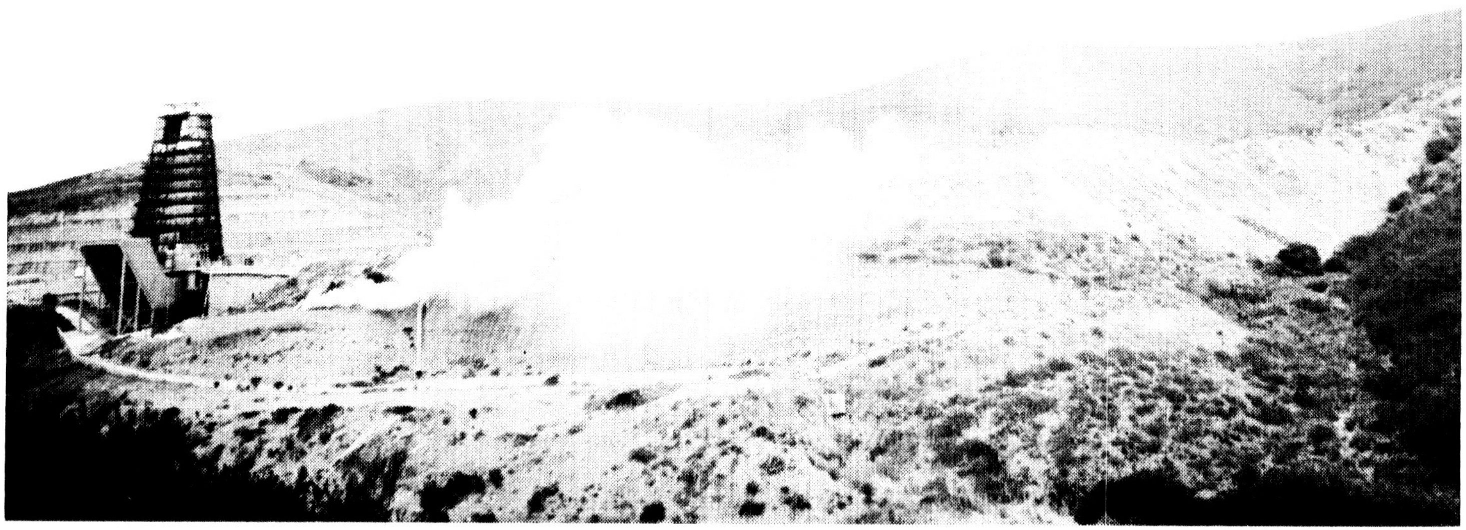


Figure 5-7. Typical Smoke Plume During LO_2 Evaporation Tests

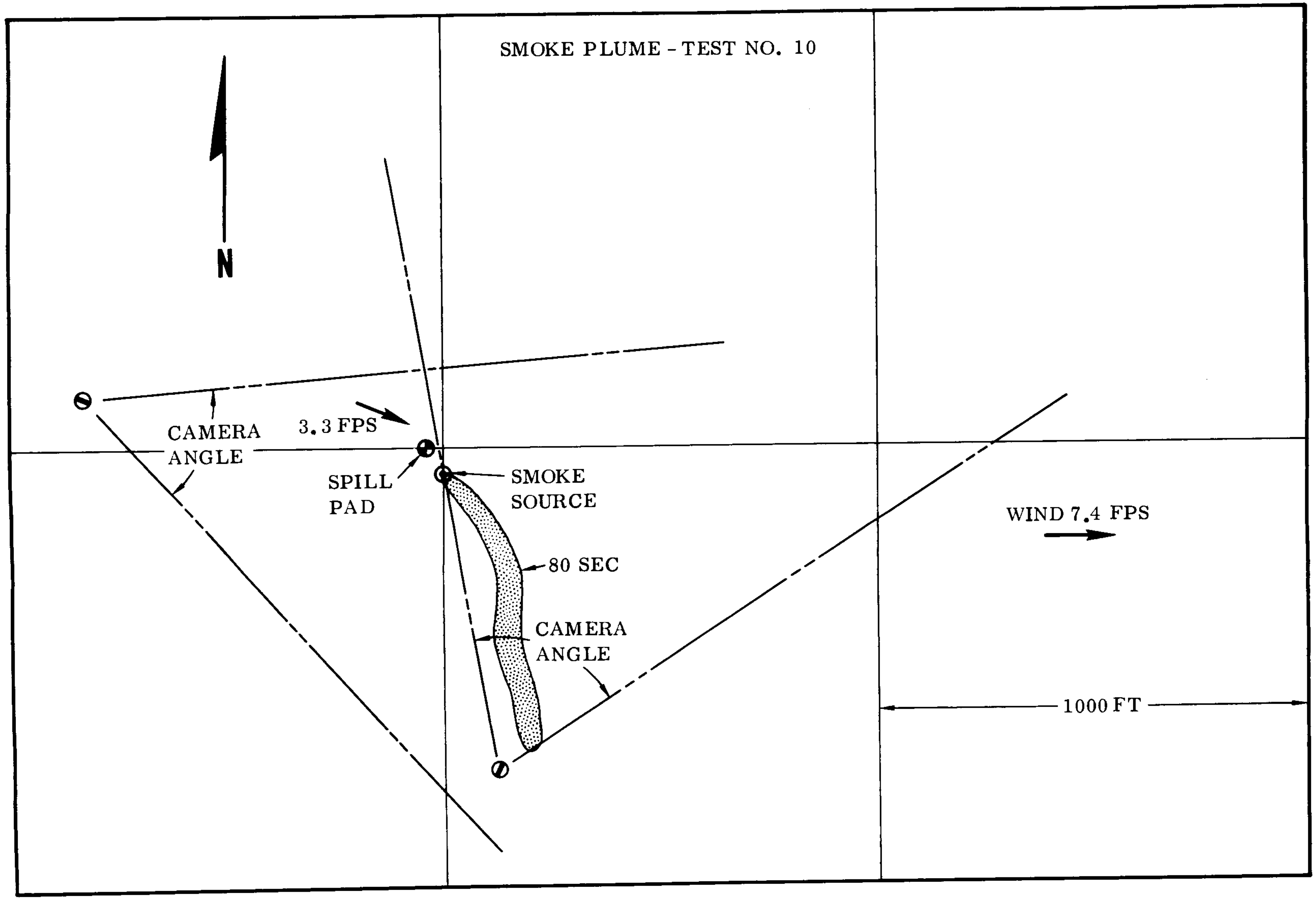


Figure 5-8. Smoke Plume Path, Test No. 10

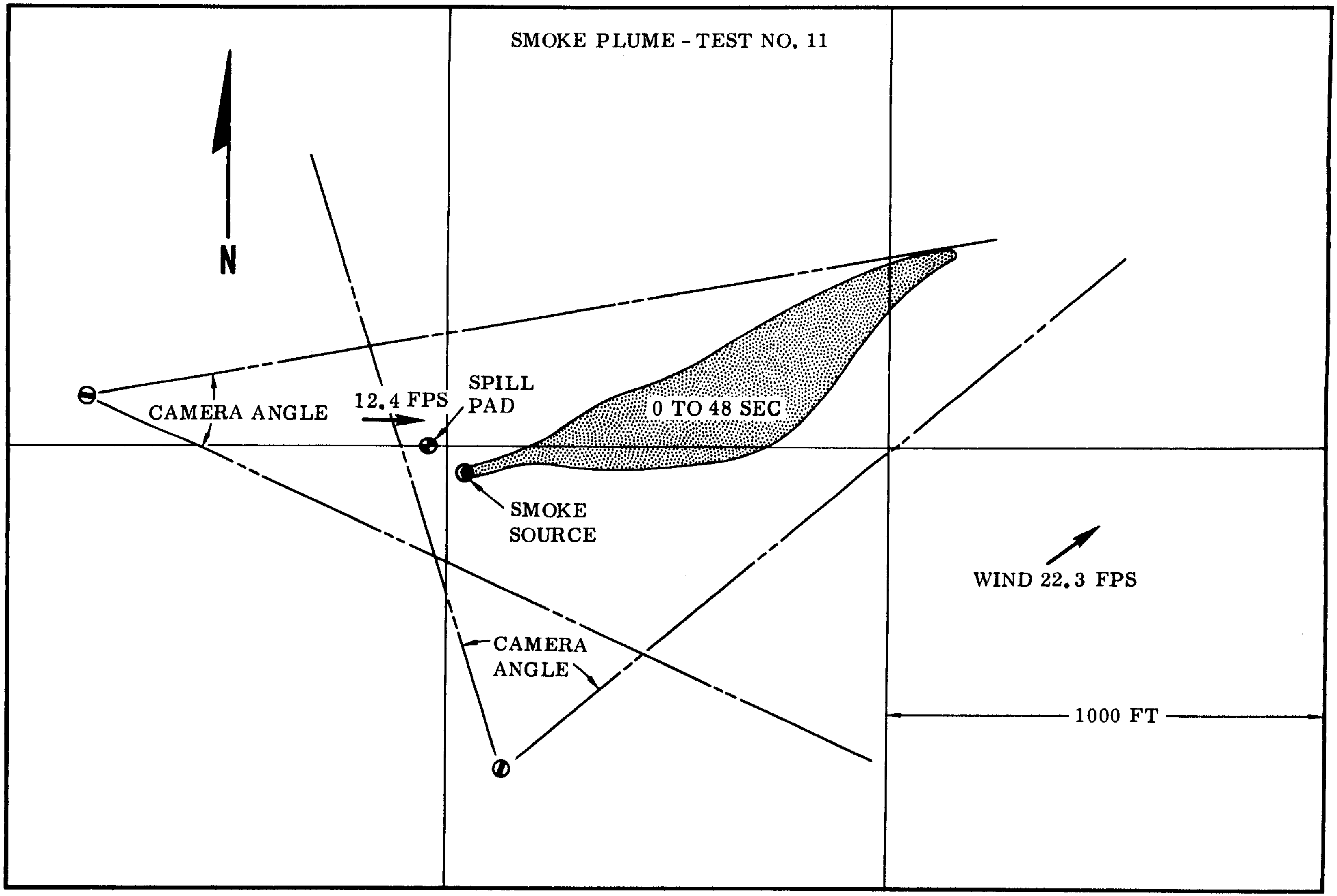


Figure 5-9. Smoke Plume Path, Test No. 11

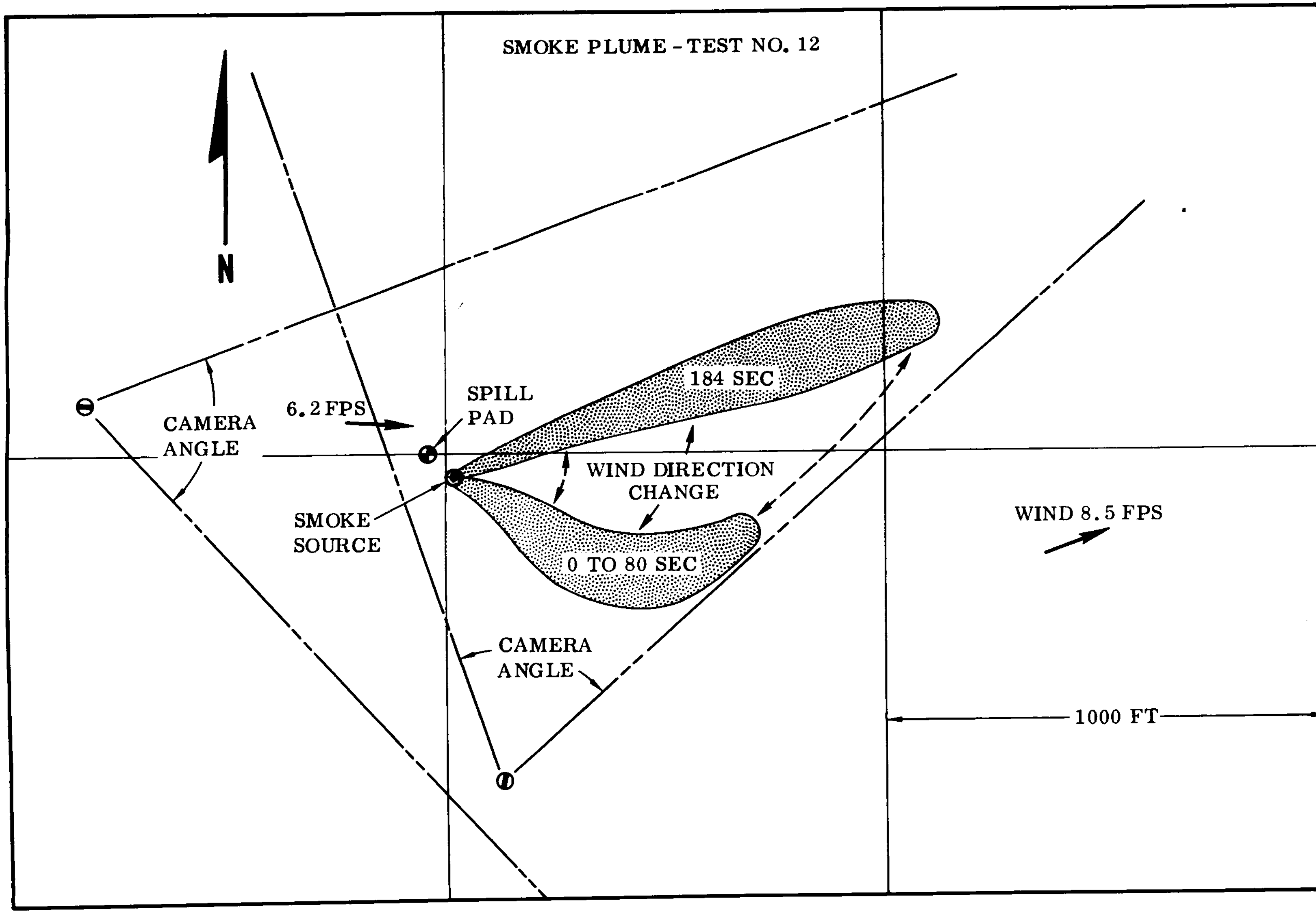


Figure 5-10. Smoke Plume Path, Test No. 12

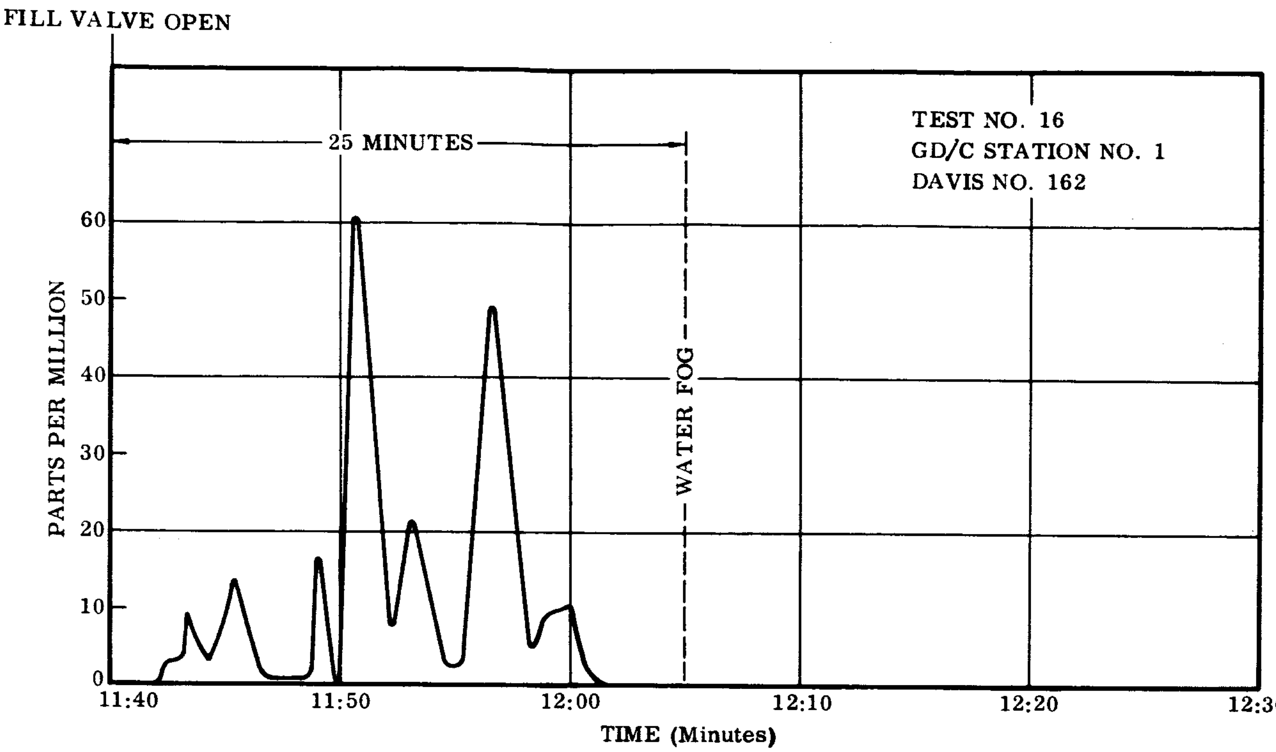


Figure 5-11. Fluorine Concentrations at Station 1, Test No. 16

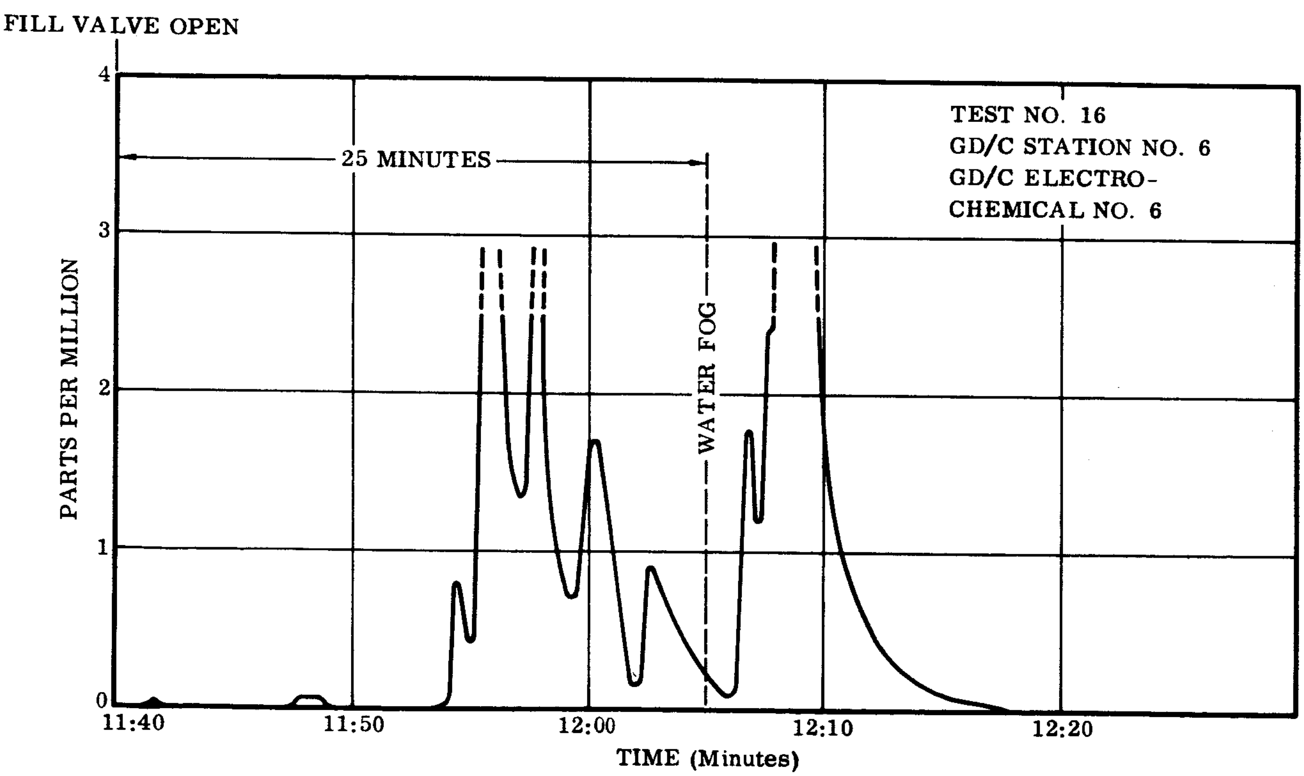


Figure 5-12. Fluorine Concentrations at Station 6, Test No. 16

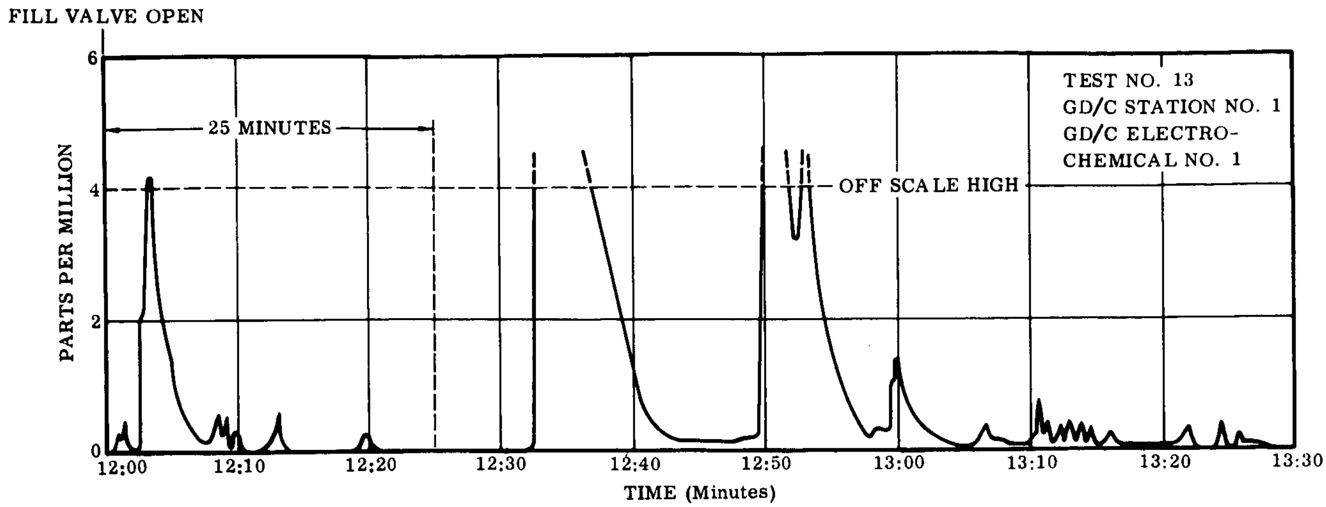


Figure 5-13. Fluorine Concentrations at Station 1, Test No. 13

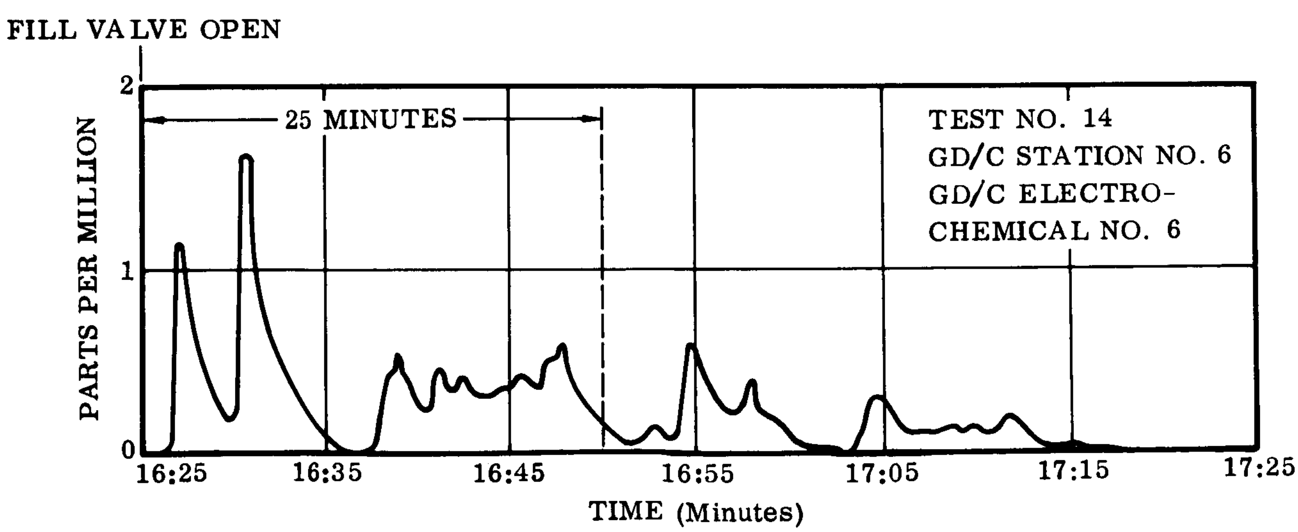


Figure 5-14. Fluorine Concentrations at Station 6, Test No. 14

The spills produced a series of hot, buoyant clouds of visible gas under various conditions of atmospheric stability. The movement of the cloud -- i.e., rise rate, direction and velocity of movement, and maximum altitude attained -- was determined by filming the trajectory. These films were supplemented by ground and aerial observations and still photographs. The diffusion characteristics following the buoyant rise were studied by injecting tracer material into the cloud and measuring the downwind tracer dosages. Simultaneous field measurements of fluorine and hydrogen fluoride dosages were correlated with the tracer dosages to provide a check on the diffusion characteristics of the cloud.

Of the eleven combustive spills, eight were successful and three failed to produce a cloud of sufficient visibility for photographing. All but one of the eight successful tests were made with charcoal as the fuel. The combustion with RP-1 fuel did not produce a visible cloud, and it was necessary to use smoke powder. A visible white cloud was produced in this manner during one test with RP-1. The cloud persistence, however, was still poor, and subsequent tests were conducted with charcoal as the fuel.

The tests provided data for correlation with theoretical calculations and extrapolation to a full-scale spill. The measured cloud rate of rise was used to establish the apparent cloud temperature differential and buoyancy with respect to the atmosphere. Before extrapolation of the theoretical calculations to those for a full-scale conflagration, it was necessary to know the energy released in the scale tests. This was determined by measuring the weight of charcoal before and after the spill to establish the quantity consumed in the combustion. A theoretical heat release from the reaction of LF_2/LO_2 with this weight of charcoal was then determined.

Temperature measurements of the fireball were provided by an instrumented pole at the spill pad. This data, in conjunction with the apparent size of the fireball from the motion pictures, was used in calculating the amount of sensible heat absorbed by the gases of the hot cloud.

During the RP-1 spills, instrumentation was provided for the measurement of overpressure resulting from the reaction with LF_2/LO_2.

1. Test Objectives

The specific test objectives of the combustive spill tests were:

a. Determine the trajectory of the hot clouds produced by the reaction of LF_2/LO_2 and fuel.

b. Determine the cloud size and horizontal and vertical velocities as a function of heat release, cloud temperature, and atmospheric stability.

c. Determine the diffusion characteristics of the cloud by injecting tracer material into the cloud and measuring the resulting downwind tracer dosage.

d. Correlate the tracer dosage measurement with field measurement for fluorine and hydrogen fluoride dosages.

e. Observe facility damage resulting from the simulated pad configuration.

f. Measure the blast characteristic of fuel/oxidizer reaction.

2. Test Procedure

Combustive Flox Spill Test Procedure 00524 (Appendix VII) was followed to transfer the LF_2/LO_2 mixture to the test tank suspended above the spill basin of charcoal or RP-1. The spill was accomplished by detonating a shaped charge to cut the bottom from the cylindrical tank, allowing the LF_2/LO_2 mixture to drop directly on the fuel. An elastic retraction cord pulled the tank bottom from the spill basin to prevent any interference with the mixing of the LF_2/LO_2 and the fuel.

Motion pictures were taken during the formation of the fireball and subsequent rise and diffusion of the hot cloud. Camera coverage was continued until the cloud could no longer be identified as a finite, measurable cloud. Tracer material was released during the combustion in a manner allowing it to be entrained in the hot cloud. The location of the tracer disseminator with respect to the spill area is shown in Figure 5-15.

Motion picture coverage of the hot cloud movement was provided by two fixed-position cameras. Initially, the cameras employed 10-mm lenses and were located approximately 800 ft from the spill pad. One was upwind of the spill pad and the other at right angles to the wind line. The 278-deg wind line was selected as representative of the average wind direction anticipated for the test period. The spill pad was used as the boresight point for both cameras. The spill pad coincided with the center of the picture frame for each camera, and the camera image planes through this point were at right angles to each other. This simplified calculations of cloud position and size from the motion pictures. Prior to the first test, however, the crosswind camera was moved to increase the downwind coverage of the cloud. This retained the camera image planes at right angles, but moved the boresight point from the spill pad.

The layout of this camera arrangement and the resulting coverage as used for tests 18 through 22 are shown in Figure 5-16. In addition to the spill pad location and the tower adjacent to the pad, a visible marker was located 500 ft downwind from the spill pad for use in determining the scale factors required to convert the measurements of the film image of the cloud to actual dimensions.

The initial tests indicated that there was inadequate camera coverage of the cloud. The cameras, therefore, were relocated to positions approximately 3000 ft from the spill pad as shown in Figure 5-17. A 5.7-mm camera was added at the crosswind position to supplement the 10-mm camera, and the crosswind cameras were rotated and elevated to improve the coverage in the downwind and vertical directions. This resulted in more elaborate calculations of cloud position and dimensions because the boresight no longer coincided with the spill pad and the camera image

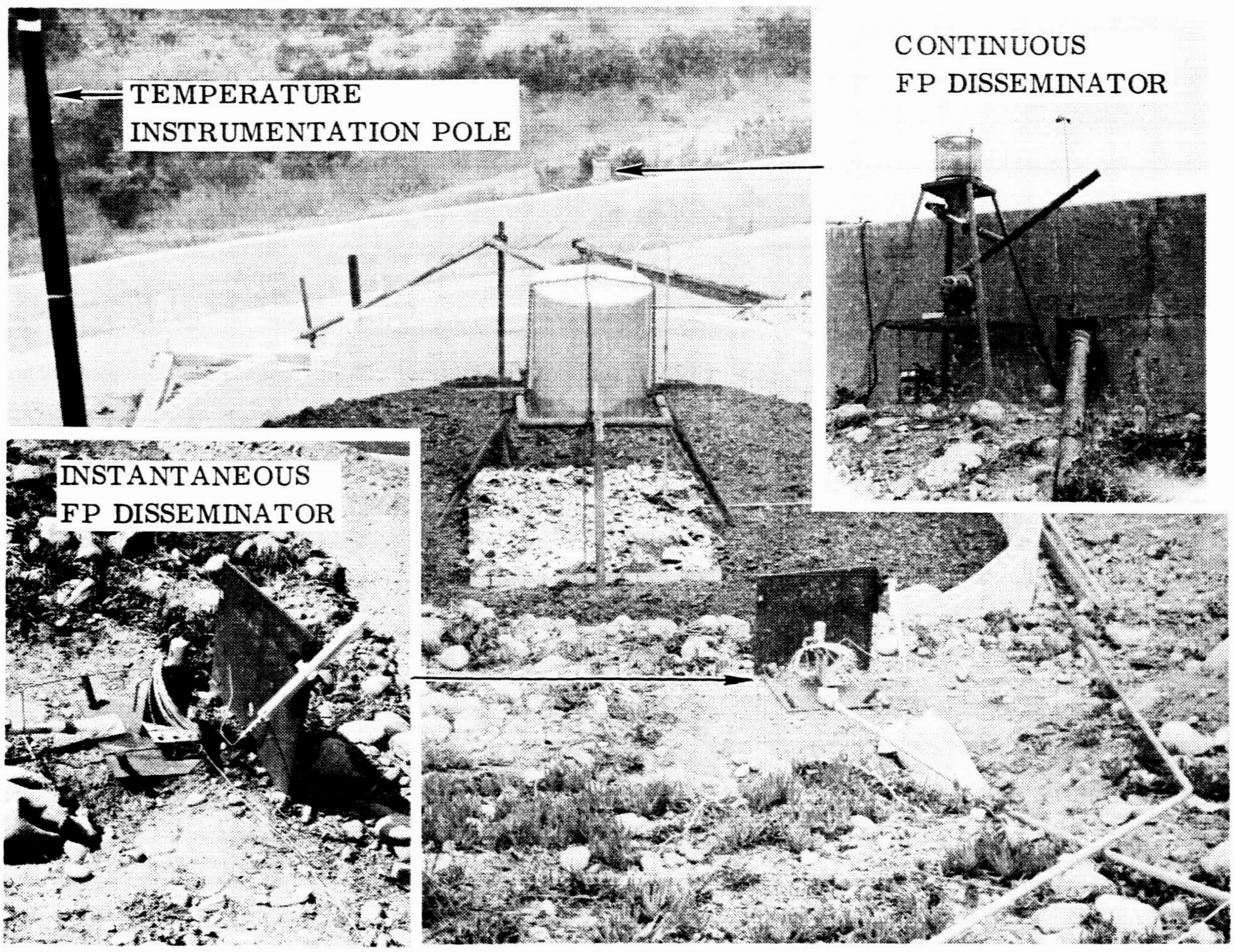


Figure 5-15. FP Tracer Disseminator

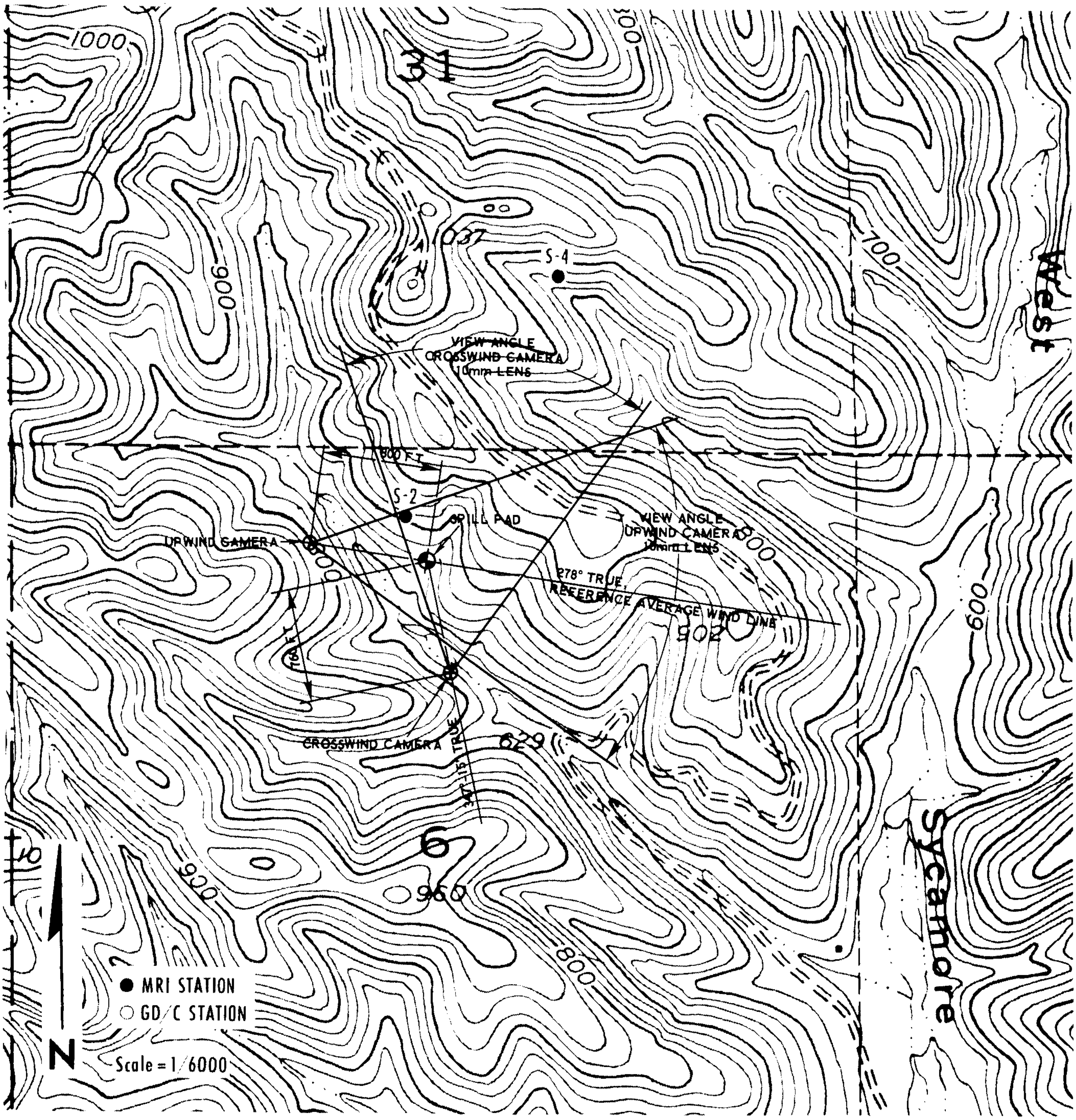


Figure 5-16. Motion Picture Camera Locations for Tests 18 through 22

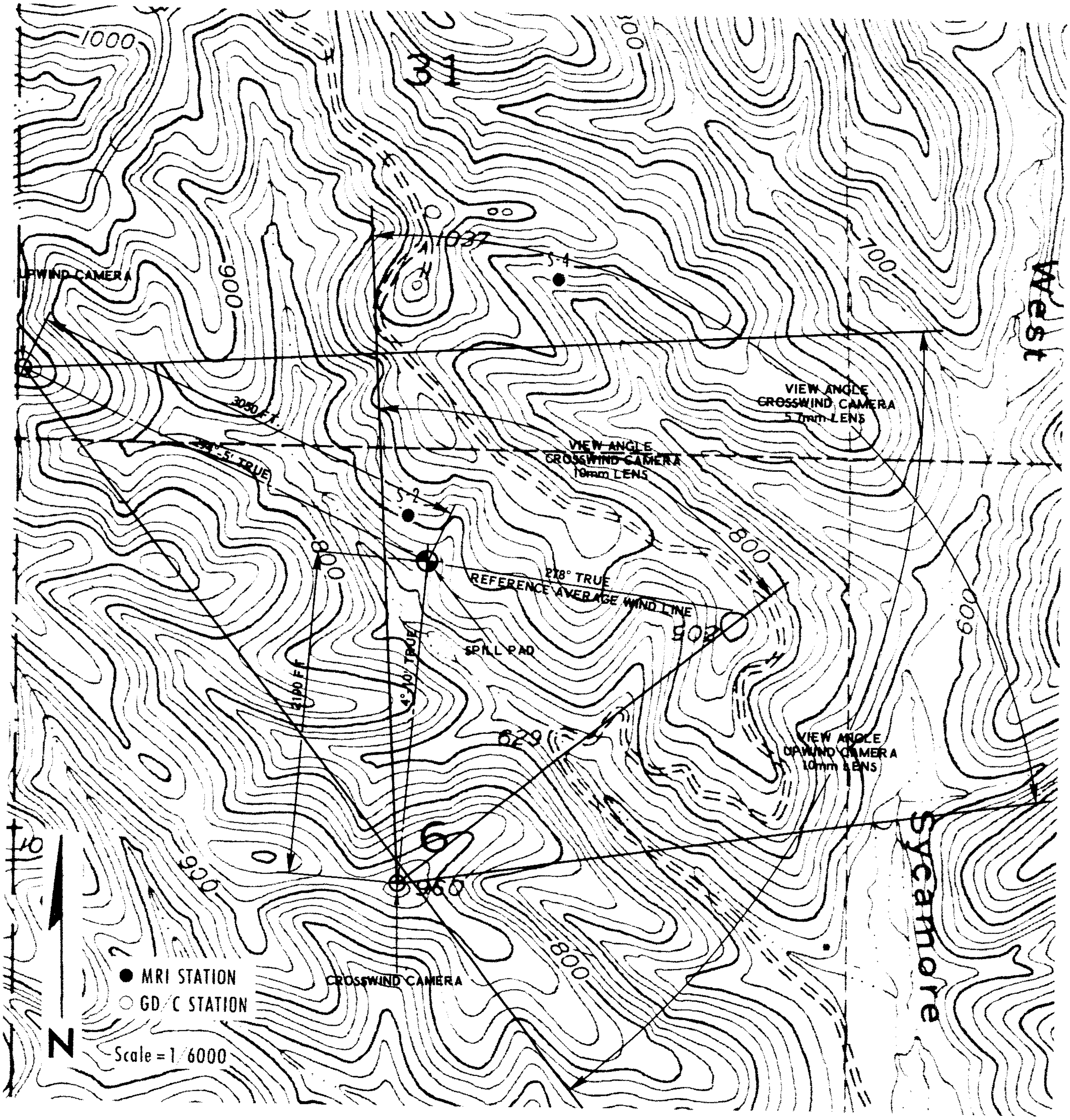


Figure 5-17. Motion Picture Camera Locations for Tests 23 through 28

planes were not at right angles. The LF_2/LO_2 spill combustion process and development of the resulting fireball were photographed with a high-speed motion picture camera. A telephoto lens and slow motion film speed of 400 frames per second provided close-up films for the first few seconds of cloud development.

3. Data Reduction

The cloud image was measured from the film, the scale factors were determined, and the position, size, velocity, and direction of motion of the cloud were computed as functions of time.

Measurements were made with the aid of a Vanguard Motion Analyzer. The film image was projected upon a screen, and movable hairlines were adjusted to locate the leading edge, trailing edge, top, and bottom of the cloud image. The film distance from fixed horizontal and vertical analyzer reference lines were recorded from the analyzer dial readings. In addition, readings were recorded for the location of the spill pad, tower, and distance marker. The frame number was recorded, and the time between selected frames determined from the film speed.

Scale factors for converting film dimensions to actual dimensions were determined by laying out the camera locations together with the spill pad, tower, and distance marker on an accurate scale contour map of the test area. From this, the actual camera angles, boresight point, and reference image planes were deduced without resorting to surveying and placing of sighting markers for each test. This proved to be important, since the camera alignment was altered for the different tests.

An IBM 7094 computer program was written to facilitate the calculation of the hot cloud dynamic characteristics. This program, included here as Table 5-4, was arranged to accept the dial readings from the Vanguard Motion Analyzer as data input. Changes in scale factors, camera alignment angles, and camera distances required new cards with revised values in the computer deck for each test. Although these factors could have been written in as data points, it did not appear to warrant a revision to the basic program for the small number of runs to be made. The program includes a correction for deviations of the camera alignment in the horizontal plane. Although the cameras were tilted up to improve vertical coverage, no correction is provided in the program for this since the error in the computed results is not significant.

Table 5-4. **Program for Determining Cloud Dimensions, Velocity, and Direction**

```
C                                  PHOTOS FRCM 2 CAMERAS
C                AXIS OF DCWNWIND CAMERA ( CAMERA 2 ) IS 280 DEGREES
C              DISTANCE TO THE LEFT CF BORESIGHT OF CAMERA 2 IS NEGATIVE
C                                          DATA FROM PHOTCS
C     X1R=MOTICN ANALYZER READING OF CLOUD RIGHT EDGE,CAMERA 1
C     X1L=MOTICN ANALYZER READING OF CLOUD LEFT  EDGE,CAMERA 1
C     Y1T=MOTICN ANALYZER READING OF CLOUD TOP        ,CAMERA 1
C     Y1B=MOTICN ANALYZER READING CF CLOUD BCTTOM     ,CAMERA 1
C     Z2R=MOTICN ANALYZER READING OF CLOUD RIGHT EDGE,CAMERA 2
C     Z2L=MOTICN ANALYZER READING OF CLOUD LEFT  EDGE,CAMERA 2
C     Y2T=MOTION ANALYZER READING OF CLOUD TOP        ,CAMERA 2
C     Y2B=MOTICN ANALYZER READING OF CLOUD BCTTOM     ,CAMERA 2
C     TDELT=TIME INTERVAL BETWEEN FRAMES,SEC.
C     D1=DISTANCE TO CAMERA 1,FT.
C     D2=DISTANCE TO CAMERA 2,FT.
C
C     CORRECTICNS TO MOTICN ANALYZER READINGS
C
C     IF RELEASE POINT DCES NOT CORRESPGND TC BORESIGHT
C     X1RP,Y1RP ARE MOTICN ANALYZER READINGS TO RELEASE POINT CAMERA 1
C     Z2RP,Y2RP ARE MOTICN ANALYZER READINGS TO RELEASE POINT CAMERA 2
C     X1BS=MOTION ANALYZER X READING TO BORESIGHT , CAMERA 1
C     Y1BS=MOTICN ANALYZER Y READING TOBORESIGHT , CAMERA 1
C     Z2BS=MCTION ANALYZER Z READING TOBORESIGHT , CAMERA 2
C     Y2BS=MOTICN ANALYZER Z READING TOBORESIGHT , CAMERA 2
      CALL START
      WOT6,110
  110 FORMAT(52H FLOX TESTS HOT CLOUD POSITION ALTITUDE AND VELOCITY)
      WOT6,80
   80 FORMAT(2X,8HCENTER X,2X,8HCENTER Z,2X,8HCENTER Y,4X,6HSIZE X,4X,6H
     1SIZE Y,4X,6HSIZE Z,2X,8HALTITUDE,2X,8HVERT VEL,2X,8HHORZ VEL,2X,8H
     2DISTANCE,1X,9HDIRECTICN,3X,7HHEADING)
      XP=0.0
      YP=0.0
      ZP=0.0
      YP1=0.0
   20 RIT5,10,X1R,X1L,Y1T,Y1B,Z2R,Z2L,Y2T,Y2B,TDELT
   10 FORMAT(9F8.3)
      IF(Y1T)100,100,70
   70 X1BS=3.416
      Y1BS=5.143
      Z2BS=3.374
      Y2BS=4.211
      X1RP=0.816
      Y1RP=2.289
      Z2RP=3.374
      Y2RP=2.176
C     CORRECTED APPARENT DISTANCE FRCM BORESIGHT
      X1RC=X1R-X1BS
      X1LC=X1L-X1BS
      Y1TC=Y1T-Y1BS
      Y1BC=Y1B-Y1BS
      Z2RC=Z2R-Z2BS
      Z2LC=Z2L-Z2BS
      Y2TC=Y2T-Y2BS
```

Table 5-4. Program for Determining Cloud Dimensions, Velocity, and Direction, Contd

```
      Y2BC=Y2B-Y2BS
C     REAL DISTANCE IN 3 PLANES
      X1SCAL=220.0
      Y1SCAL=220.0
      Z2SCAL=177.0
      Y2SCAL=177.0
      DXR=X1RC*X1SCAL
      DXL=X1LC*X1SCAL
      D1YT=Y1TC*Y1SCAL
      D1YB=Y1BC*Y1SCAL
      DZR=Z2RC*Z2SCAL
      DZL=Z2LC*Z2SCAL
      D2YT=Y2TC*Y2SCAL
      D2YB=Y2BC*Y2SCAL
C     COMPUTE APPARENT CENTER OF CLOUD IN X AND Z DIRECTIONS
      DXC=DXL+(DXR-DXL)/2.0
      DZC=DZL+(DZR-DZL)/2.0
      D1=770.0
      D2=1300.0
      ANGLEA=18.0
      XD1=D1*SINF(ANGLEA)
      ZD1=D1*COSF(ANGLEA)
      ANGLEB=ATANF(DXC/D1)
      XA=DXC*COSF(ANGLEA)
      P=DXC*SINF(ANGLEA)
      ANGLEC=ANGLEA+ANGLEB
      H=P/COSF(ANGLEC)
      XB=H*SINF(ANGLEC)
      XCOR=XA+XB
C
      XCENT=(XCOR-DZC*(XCOR+XD1)/ZD1)/(1.0+DZC*(XCOR+XD1)/(ZD1*D2))
      ZCENT=(XCENT+D2)*DZC/D2
      D1APR=(DXC**2.0+D1**2.0)**0.5
      D2APR=(DZC**2.0+D2**2.0)**0.5
      D2REAL=(ZCENT**2.0+(D2+XCENT)**2.0)**0.5
      D1REAL=((XCENT+XD1)**2.0+(ZD1-ZCENT)**2.0)**0.5
      Y1DIST=D1YT*D1REAL/D1APR
      Y1DISB=D1YB*D1REAL/D1APR
      Y2DIST=D2YT*D2REAL/D2APR
      Y2DISB=D2YB*D2REAL/D2APR
      Y1CENT=Y1DISB+(Y1DIST-Y1DISB)/2.0
      Y2CENT=Y2DISB+(Y2DIST-Y2DISB)/2.0
      Y1DRP=(Y1BS-Y1RP)*Y1SCAL+Y1CENT
      Y2DRP=(Y2BS-Y2RP)*Y2SCAL+Y2CENT
      Y1TRP=(Y1BS-Y1RP)*Y1SCAL+Y1DIST
      Y1BRP=(Y1BS-Y1RP)*Y1SCAL+Y1DISB
      Y2TRP=(Y2BS-Y2RP)*Y2SCAL+Y2DIST
      Y2BRP=(Y2BS-Y2RP)*Y2SCAL+Y2DISB
      YTOP=(Y1TRP+Y2TRP)/2.0
      YBOT=(Y1BRP+Y2BRP)/2.0
      YCENT=(Y1DRP+Y2DRP)/2.0
      XSIZE=(DXR-DXL)*D1REAL/D1APR
      YSIZE=YTOP-YBOT
      ZSIZE=(DZR-DZL)*D2REAL/D2APR
      CENTX=(X1BS-X1RP)*X1SCAL+XCENT
      CENTY=YCENT
```

Table 5-4. Program for Determining Cloud Dimensions, Velocity, and Direction, Contd

```
      CENTZ=(Z2BS-Z2RP)*Z2SCAL-ZCENT
C     ALTITUDE OF CENTER OF CLOUD
      ALTP=725.C
      ALT =CENTY+ALTP
C     CLOUD VELCCITY AND DIRECTICN
      VELX=(CENTX-XP)/TDELT
      VELY=(YTOP-YP1)/TCELT
      VELZ=(CENTZ-ZP)/TCELT
      XP=CENTX
      YP=CENTY
      ZP=CENTZ
      YP1=YTCP
      VHOR=(VELX**2.0+VELZ**2.0)**0.5
      DISH=(CENTZ**2.0+CENTX**2.C)**C.5
      DIR=ATANF(VELZ/VELX)*57.29
      DIRA=278.C+DIR
   60 WOT6,50,CENTX,CENTZ,CENTY,XSIZE, YSIZE,ZSIZE,ALT,VELY,VHOR,DISH,
     1DIR,DIRA
   50 FORMAT(12F10.1)
      GO TO 20
  100 CALL EXIT
      END(1,1,0,1,0,0,1,1,0,1,0,0,0,0,0)
```

4. Results

Results of the hot source tests are discussed under four headings: Cloud Data, Energy Release and Cloud Temperature, Correlation with Theory, and Fluorine and Hydrogen Fluoride Concentration.

a. Cloud Data

The dynamic characteristics of the cloud resulting from the combustive spill of the LF_2/LO_2 are presented in Figures 5-18 through 5-49. The combustive spills were characterized by a fireball resulting in a hot cloud having an initial vertical velocity of approximately 15 to 25 ft/sec, which decreased rapidly as the cloud expanded and lost its buoyant energy. The subsequent vertical rise of the cloud was then controlled primarily by the atmospheric stability condition.

Cloud position is shown by the three coordinates from the release point to the cloud center: downwind distance, elevation above release point, and crosswind distance. The size of the cloud is described by dimensions in the downwind, crosswind, and vertical directions. The cloud velocity is given as the vertical and horizontal (i.e., downwind) component of the instantaneous cloud velocity. The direction of cloud motion in the horizontal plane is given as a compass heading. The downwind direction is defined for each test by a reference wind line that coincides with the boresight line of the upwind camera. All the cloud characteristics shown are correlated as a function of time from the release of the cloud.

In tests 18 through 24 an unstable temperature gradient existed throughout the observed vertical movement of the cloud, which continued to rise until visibility was lost due to diffusion. In none of these tests was the cloud observed to reach the altitude where a temperature inversion existed. It was apparent from the low vertical velocity of the cloud at maximum observed altitude that there was not sufficient buoyant energy left to penetrate the inversion layer. In test 25 the cloud completely penetrated into the inversion layer, but it had no significant buoyant energy left at the last point observed.

Only in test 26 did the cloud appear to have appreciable energy left when it reached the inversion level. It maintained a vertical velocity of 11 ft/sec up to the maximum altitude at which it was visible from the motion picture stations. At this altitude, the top of the cloud had penetrated approximately 200 ft into the inversion layer.

In test 27 a temperature inversion existed approximately 1300 ft above the spill pad, and the cloud was observed to level off and dissipate at this altitude. The quantity of charcoal consumed and the resulting initial cloud velocity was only about half those of the previous test. This, coupled with the rather strong temperature inversion, accounts for the apparent lack of penetration of the inversion by the hot cloud.

Test 28 was run under conditions very similar to those of test 27. The cloud again reached approximately 750 ft above the spill pad, with only partial penetration of the inversion layer. The top of the cloud remained at this altitude, with the center and bottom of the cloud apparently descending due to continued diffusion.

In tests 25 through 28 the cloud, or at least sections of it, were reported to have been observed from the aircraft to be at considerably higher altitudes than recorded by the ground cameras. Cross sections of the measured clouds were plotted on a relief map of the test area along with the inversion heights and maximum cloud height observed from the aircraft. This data is presented on page 57 of Part 2.

b. Energy Release and Cloud Temperature

An estimate of the energy released during the combustive spills (tests 24 through 28) is shown in Table 5-5. The calculation of a minimum and maximum probable energy release was based on the weight of charcoal consumed in the reaction. The heat produced per pound of charcoal consumed is dependent upon the completeness of the oxidization process. Assuming that LO_2 combines with charcoal to form CO_2, and LF_2 combines with charcoal to form CF_4, the theoretical heat release would be approximately 17,000 Btu per lb of charcoal. The estimate of minimum heat release from the FLOX-charcoal reaction is

Table 5-5. Maximum Energy Release - Combustive Spills

TEST NO.	CHARCOAL CONSUMED (lb)	(percent)	HEAT RELEASE (Btu $\times 10^{-6}$) (min)	(max)	INITIAL CLOUD VELOCITY (ft/sec)
24	320	25.6	2.24	5.44	23
25	245	16.3	1.71	4.17	21
26	214	14.3	1.50	3.64	16
27	110	7.3	0.77	1.87	11
28	134	8.9	0.93	2.27	15

based on gas analyses from small-scale tests at Convair where larger amounts of CO and CO_2 were found along with high molecular weight fluorocarbons ($-CF_{2-(X)}$) and a little CF4. On the basis of these tests, the lower limit of heat release would be approximately 7000 Btu per lb of charcoal. The minimum value actually may be somewhat higher due to the effects of stay time of the reactants and the size of the reaction, but 7000 Btu is considered a minimum limit. These two values are used to determine a range from minimum to maximum probable heat release.

The initial velocity of the hot cloud produced is also listed in Table 5-5. There appears to be a qualitative relation between the heat release and velocity of the resulting cloud. However, this is not a necessary relation, since the size of the cloud varied for the different tests. Early cloud size is not available for most of the runs because the fireball exceeded the field of view of the high speed movie camera.

Temperature data obtained from the instrumentation pole at the spill pad is shown in Figures 5-50 through 5-58. Temperature was not measured until the fireball had expanded to envelop the pole because the instrumentation pole was approximately 20 ft from the center of the spill.

In the first combustive spills, small quantities of LF_2/LO_2 were dropped, and the fireball was relatively small. Although the combustion

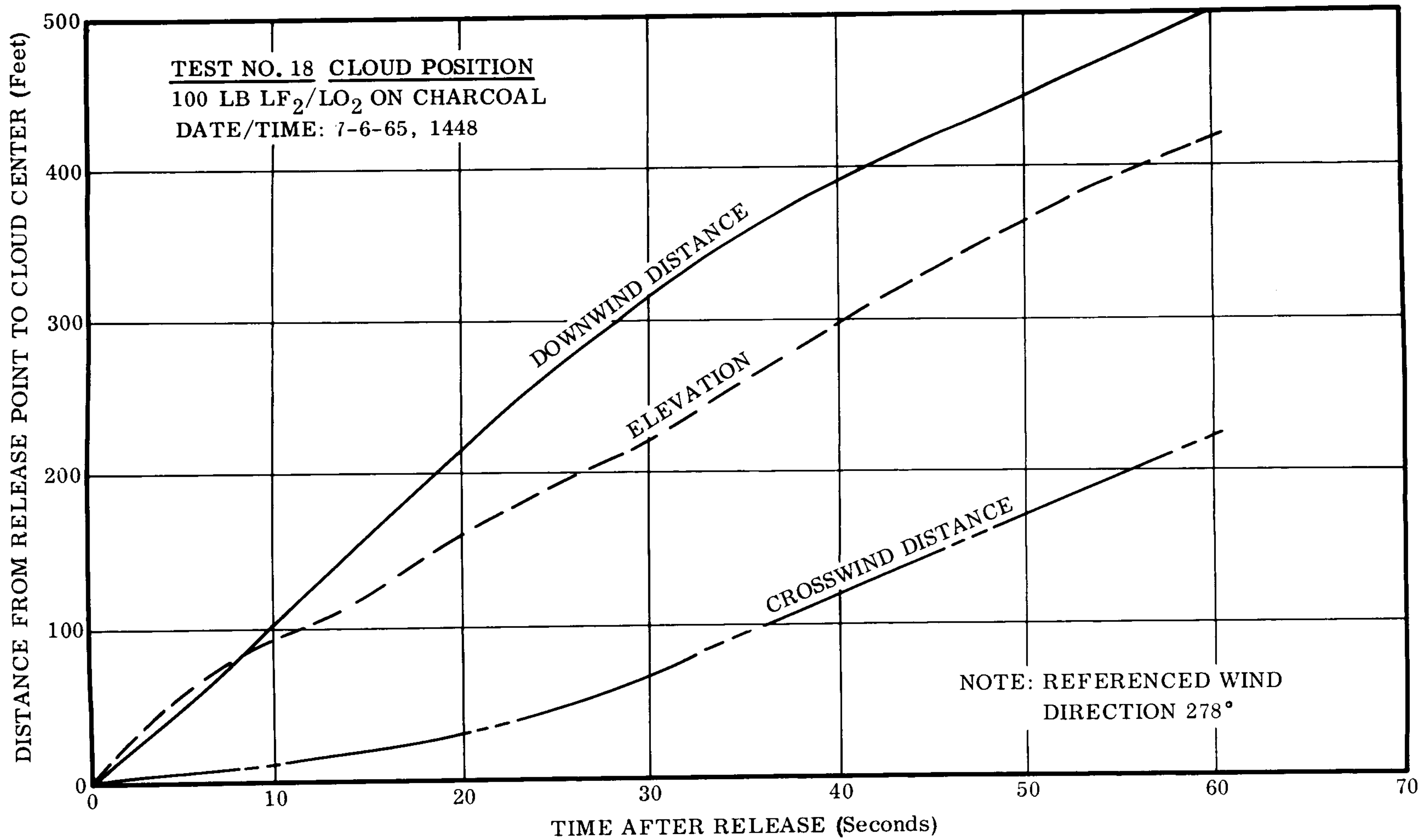


Figure 5-18. Test No. 18 Cloud Position

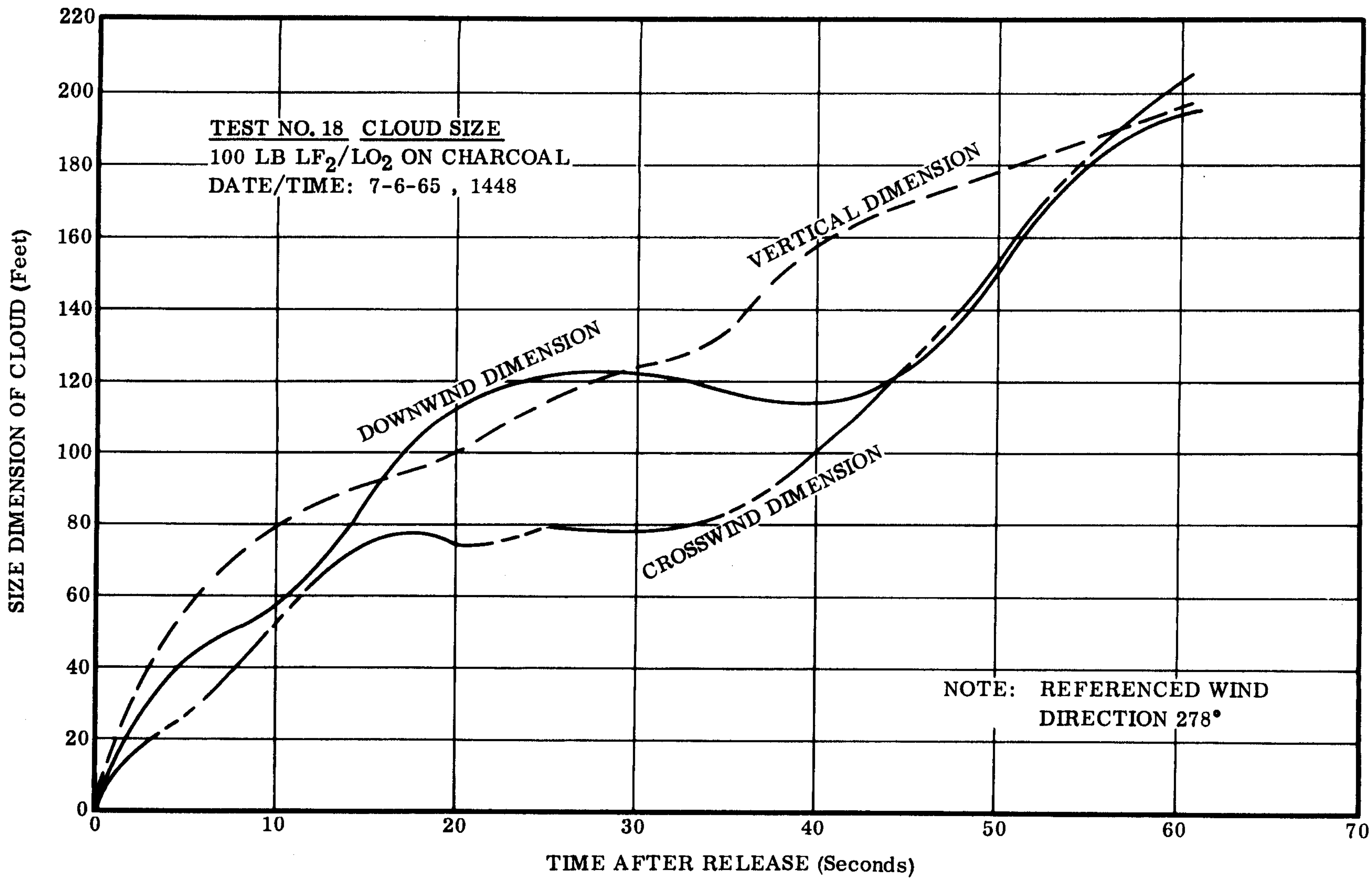


Figure 5-19. Test No. 18 Cloud Size

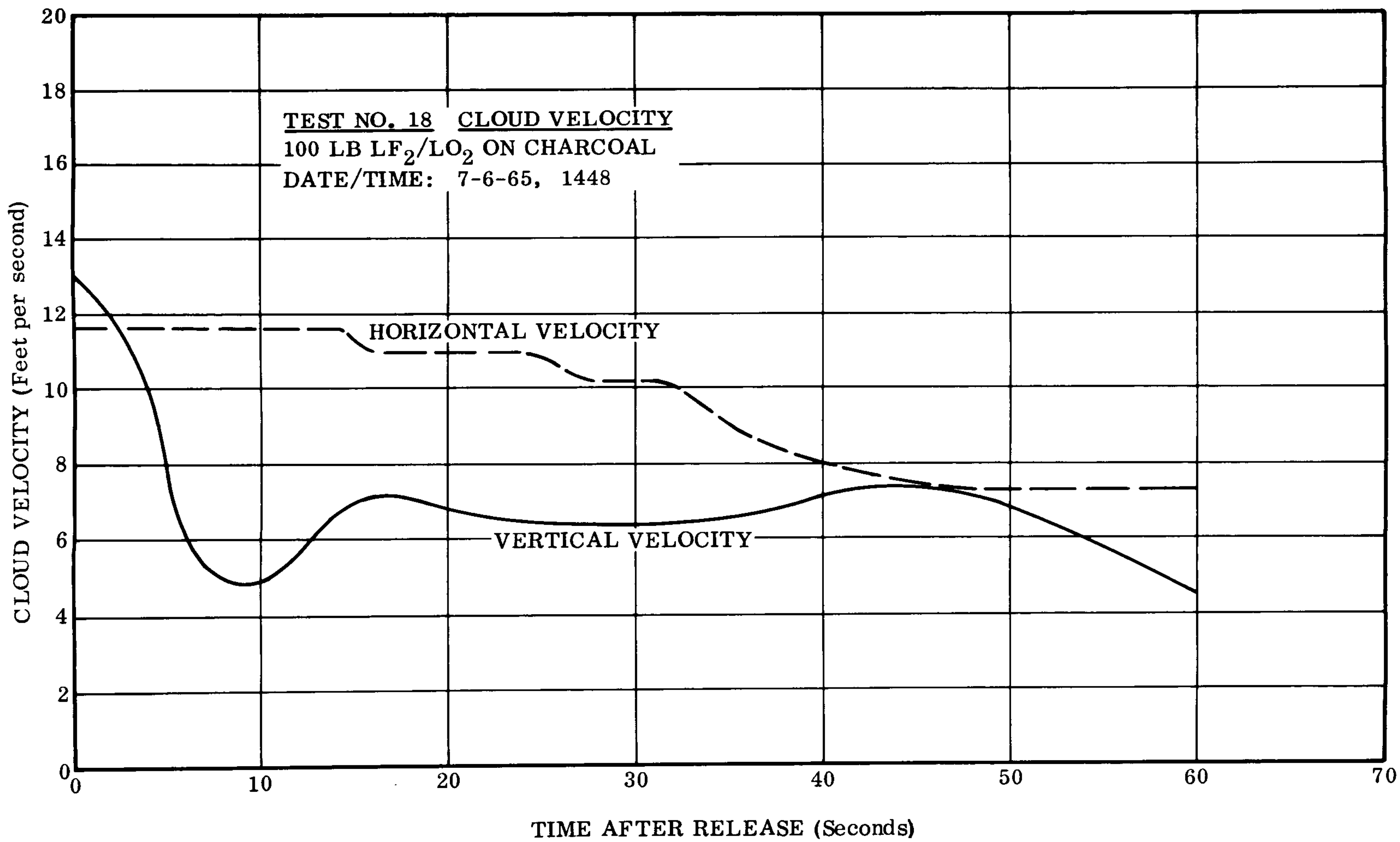


Figure 5-20. Test No. 18 Cloud Velocity

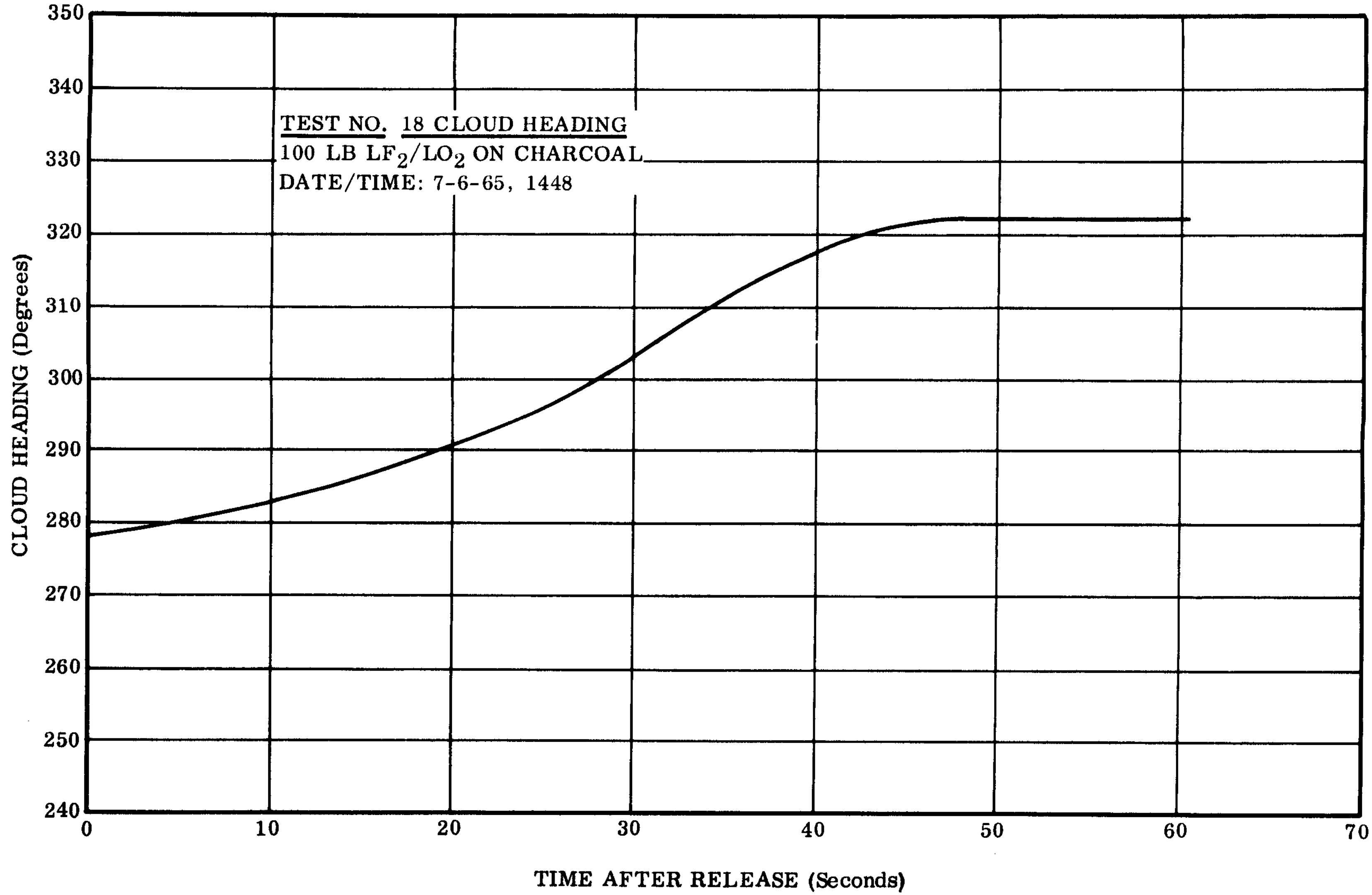


Figure 5-21. Test No. 18 Cloud Heading

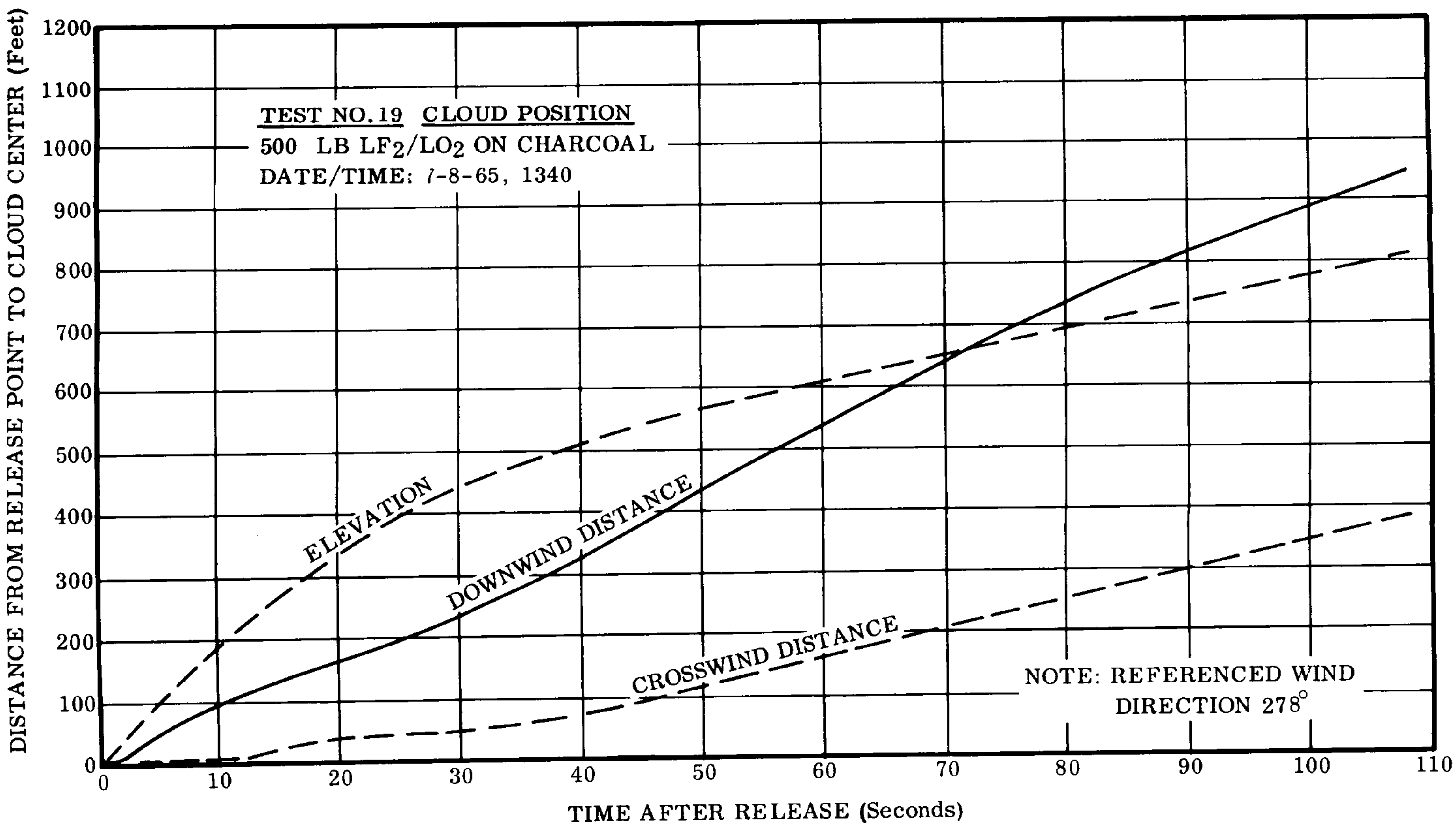


Figure 5-22. Test No. 19 Cloud Position

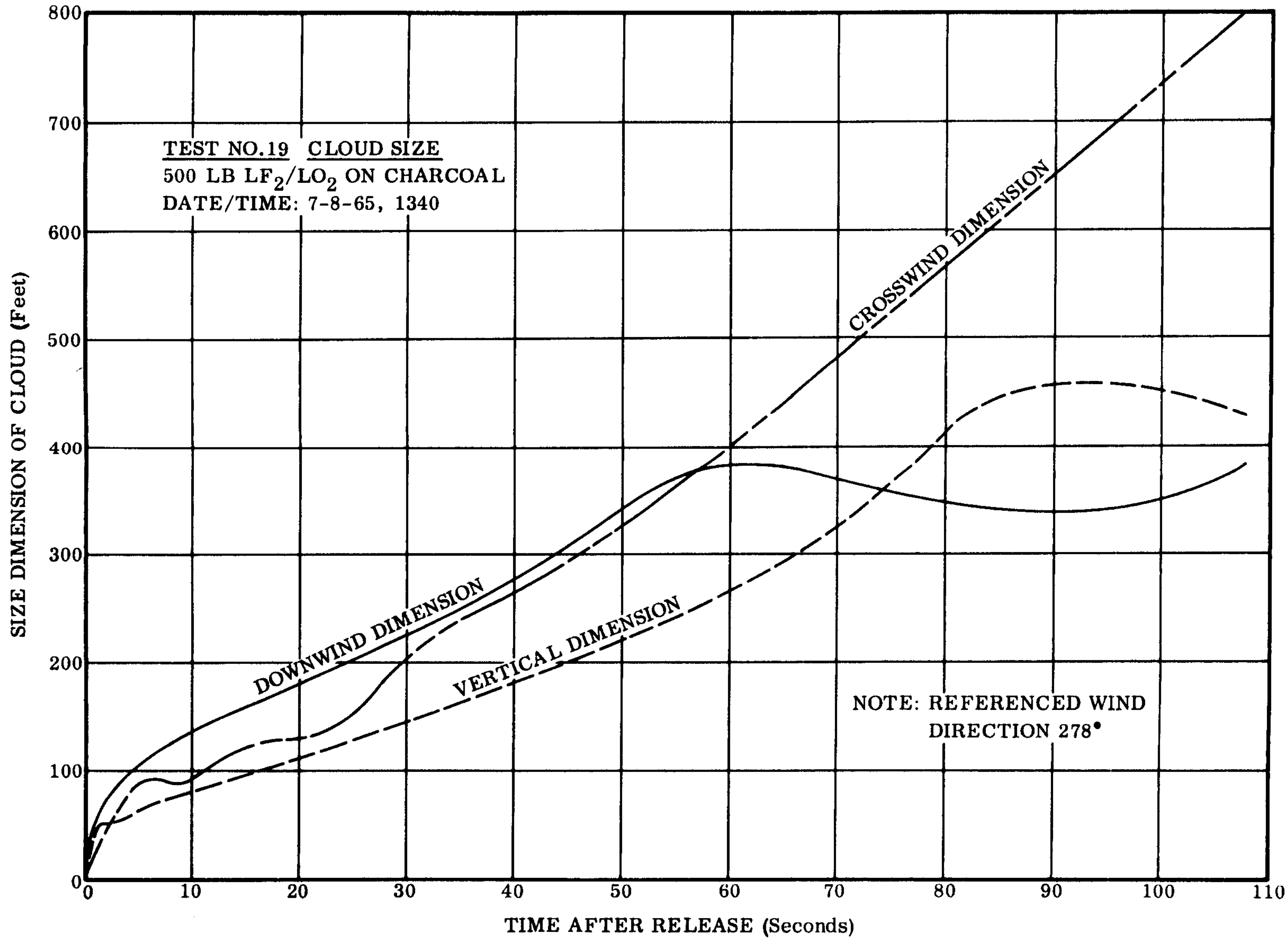


Figure 5-23. Test No. 19 Cloud Size

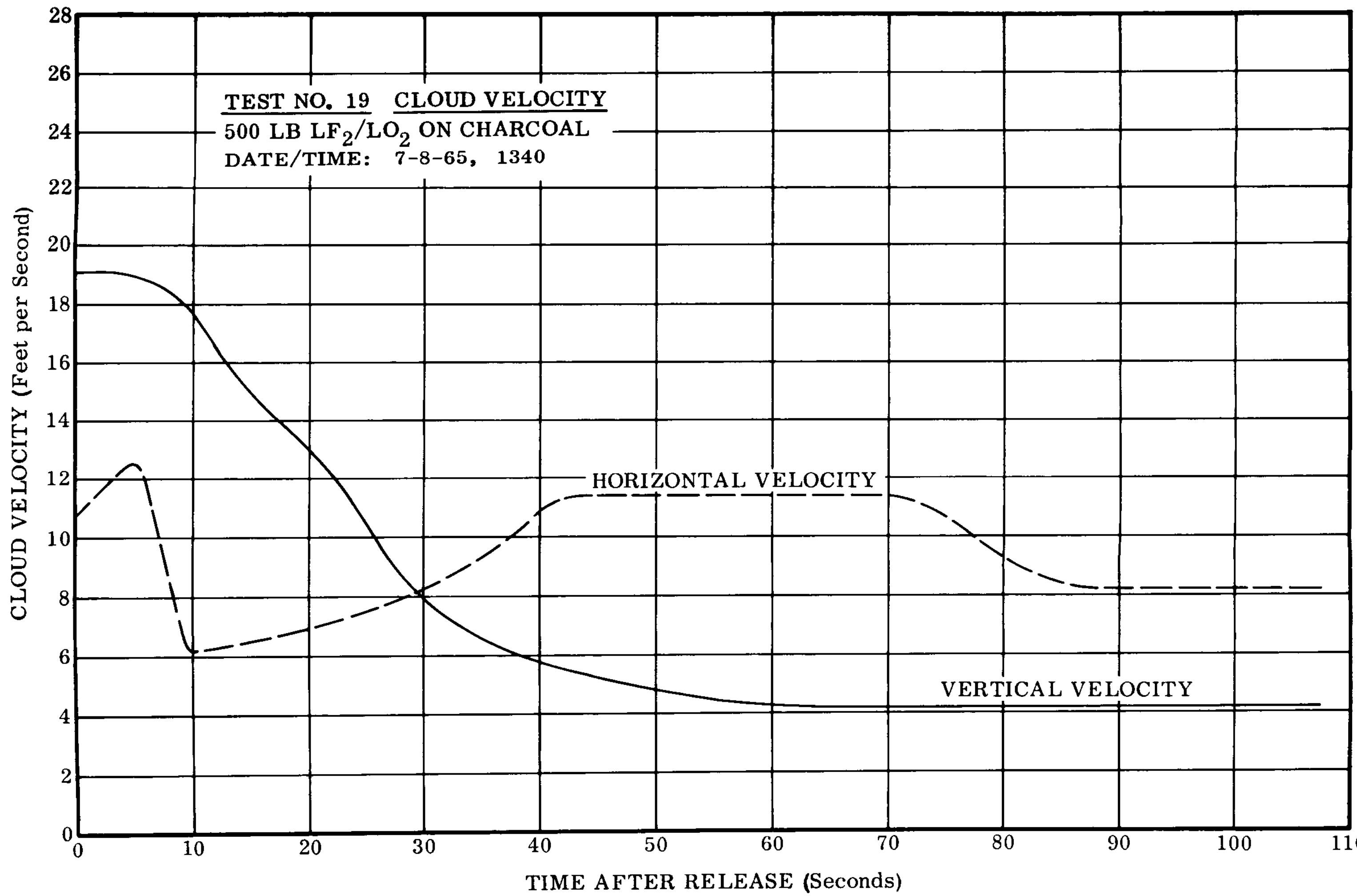


Figure 5-24. Test No. 19 Cloud Velocity

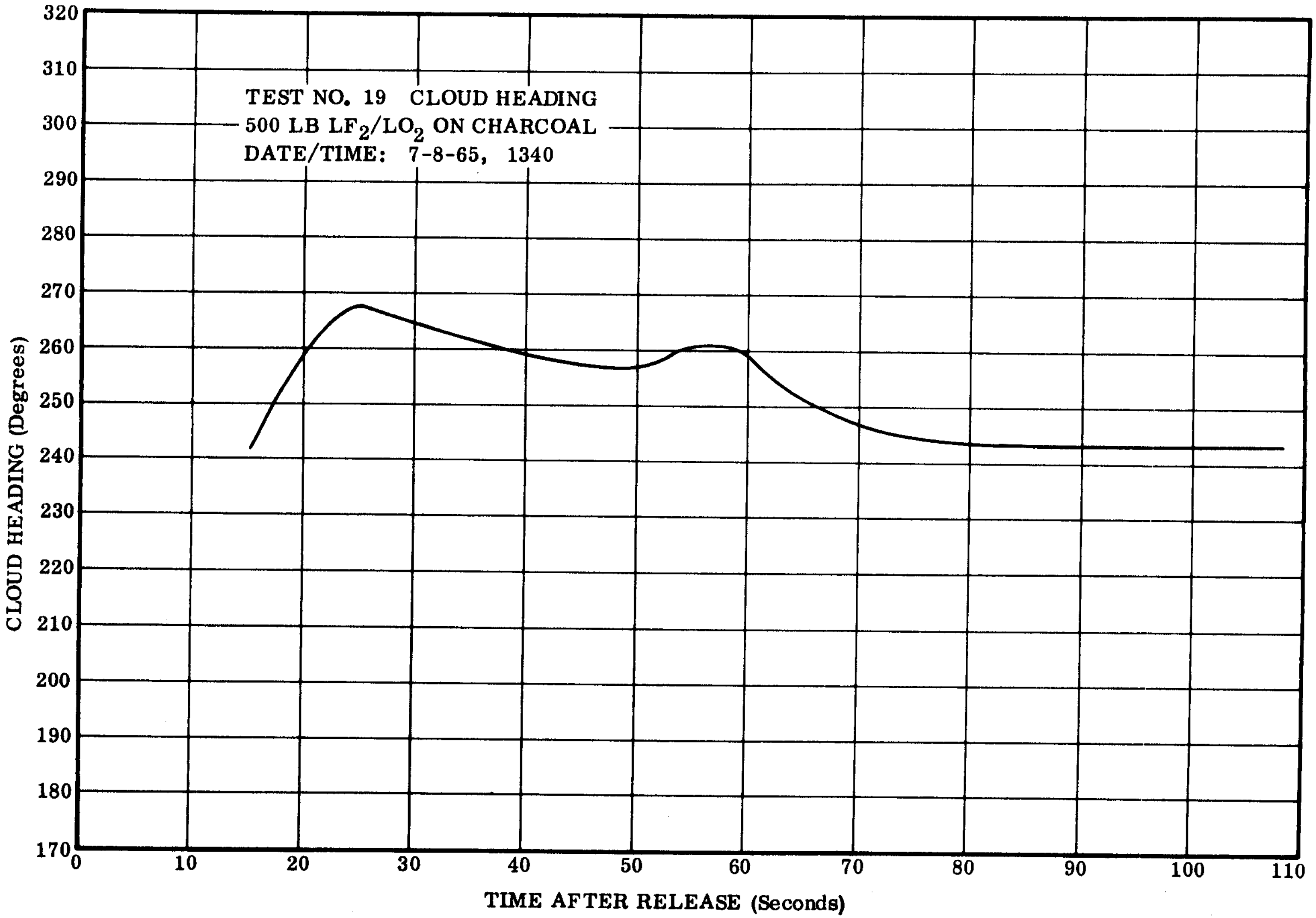


Figure 5-25. Test No. 19 Cloud Heading

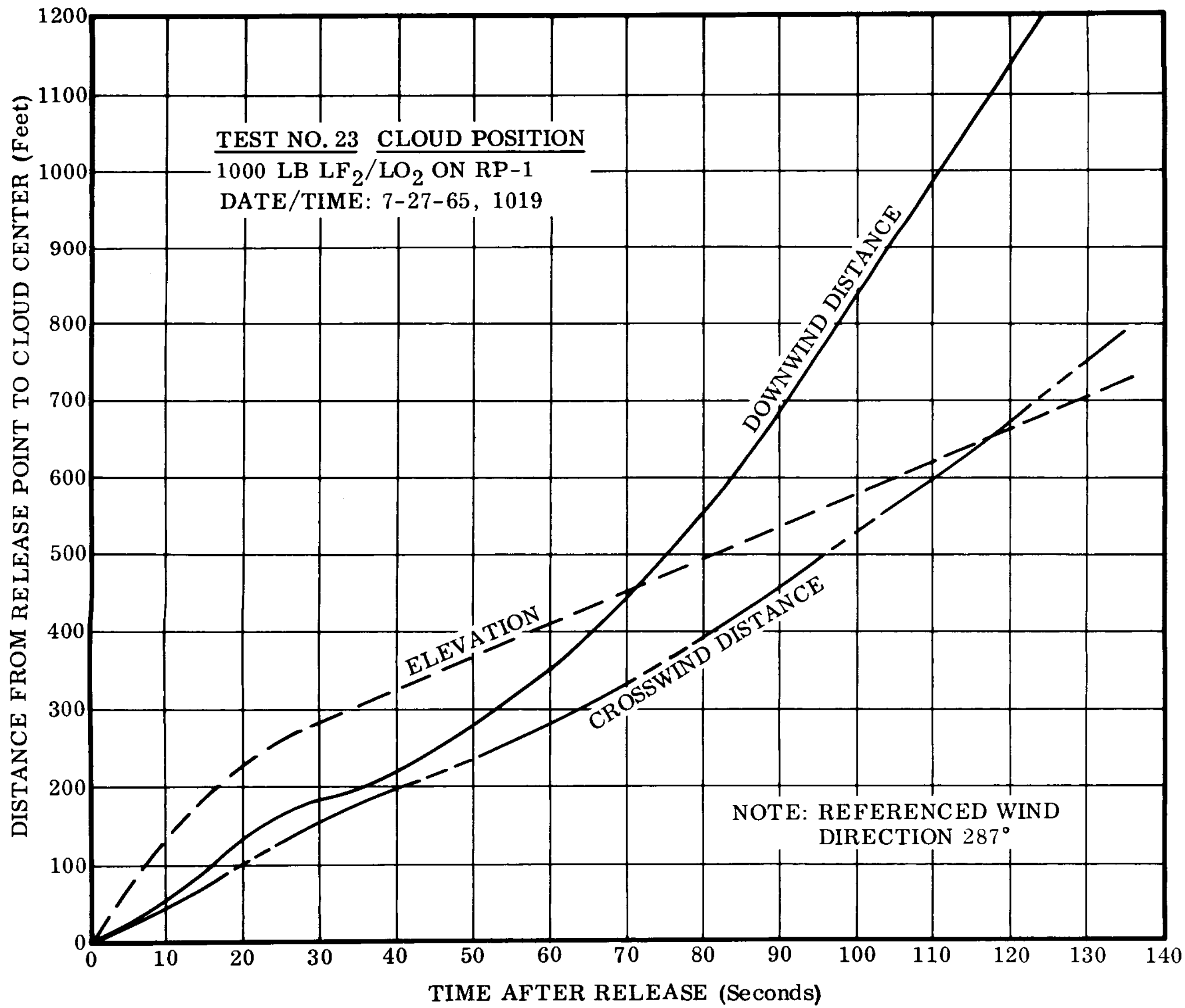


Figure 5-26. Test No. 23 Cloud Position

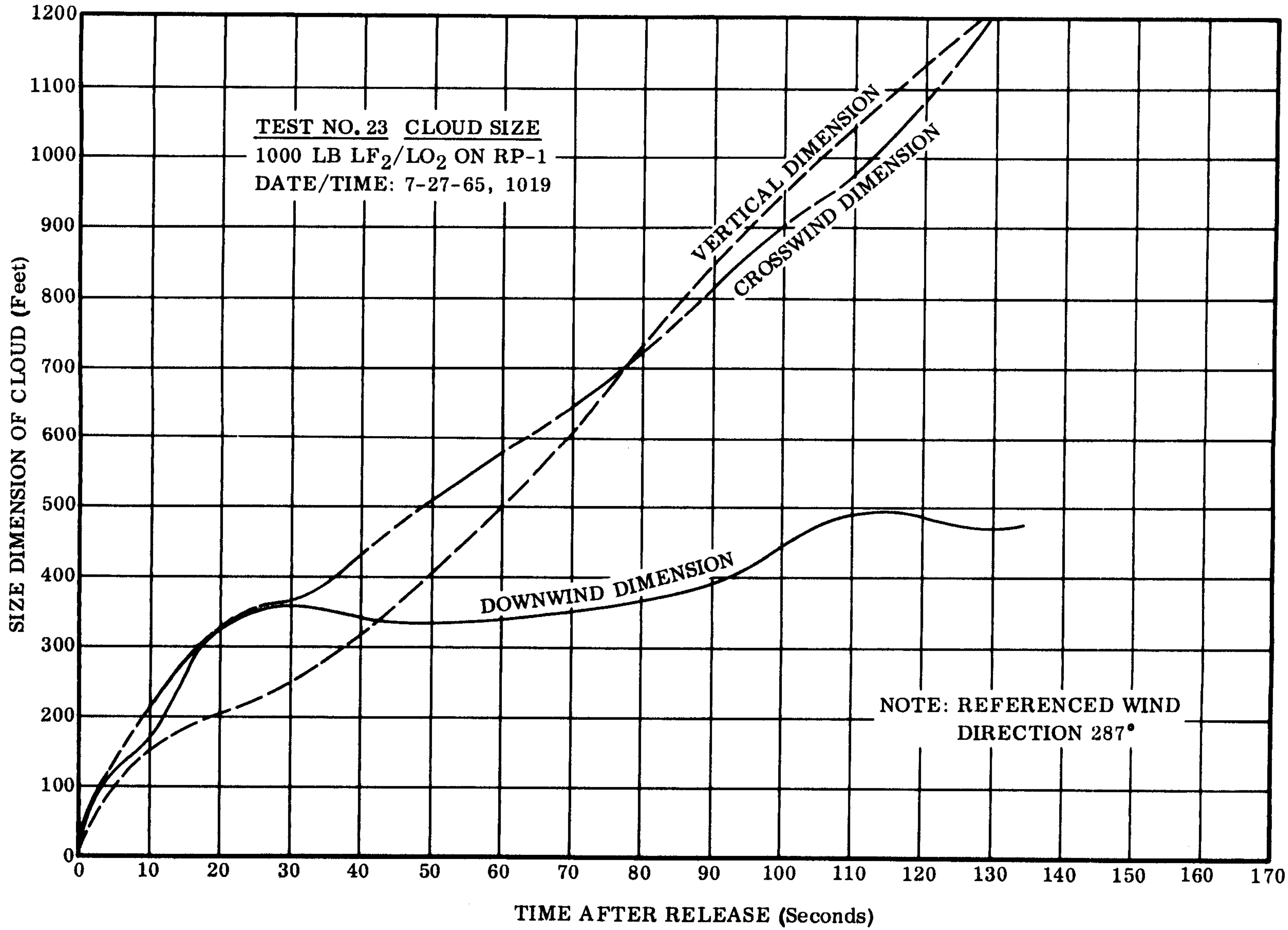


Figure 5-27. Test No. 23 Cloud Size

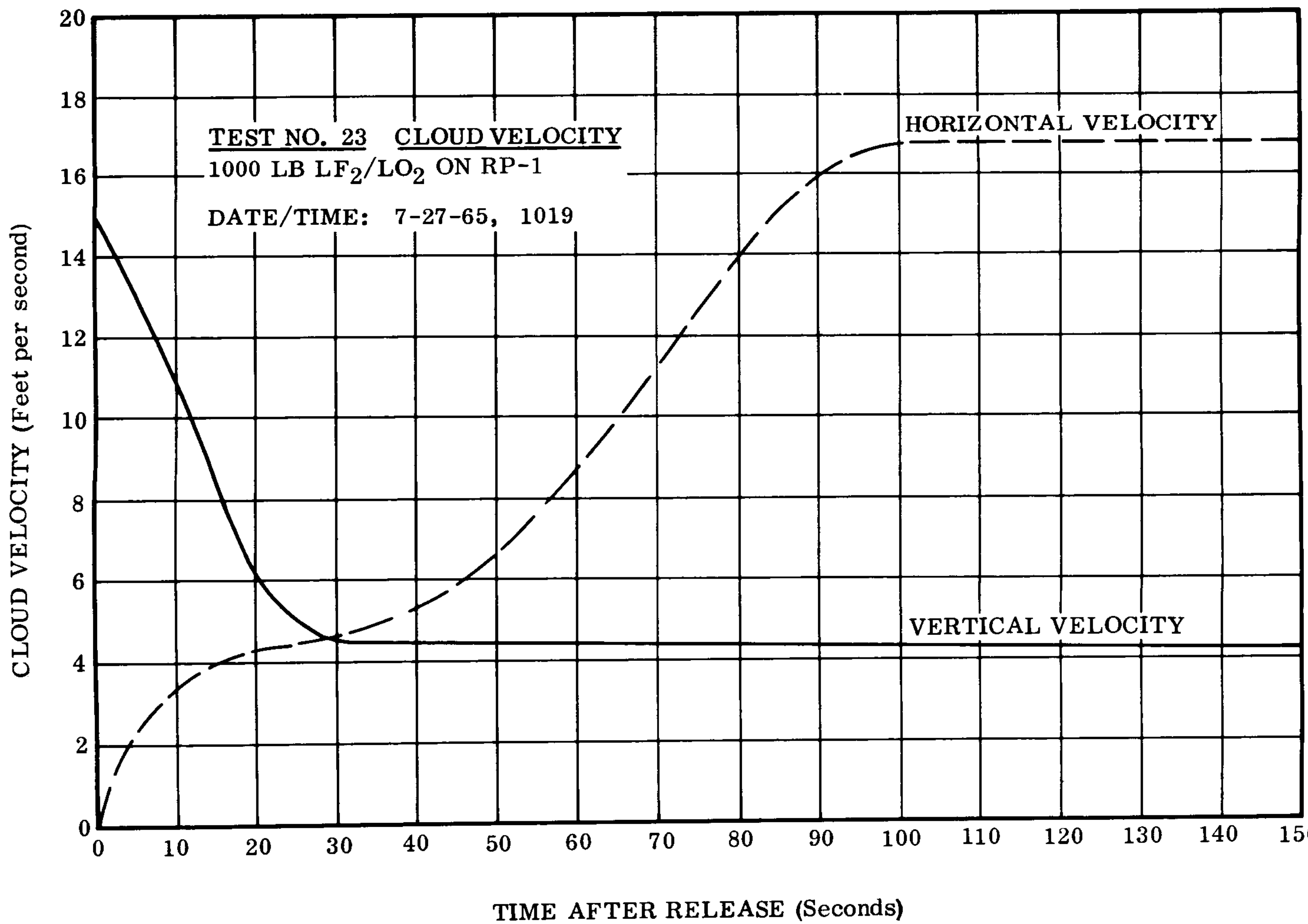


Figure 5-28. Test No. 23 Cloud Velocity

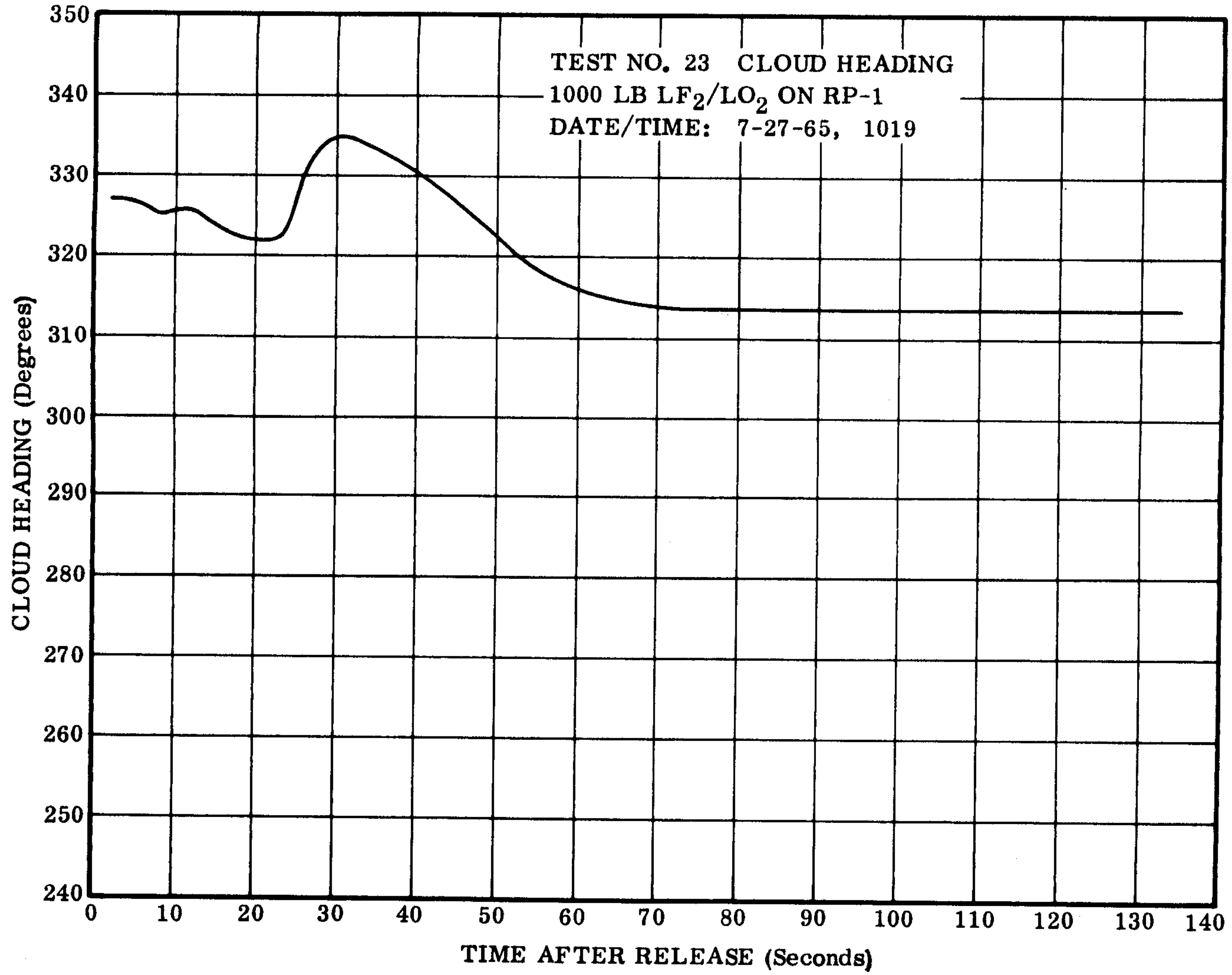


Figure 5-29. Test No. 23 Cloud Heading

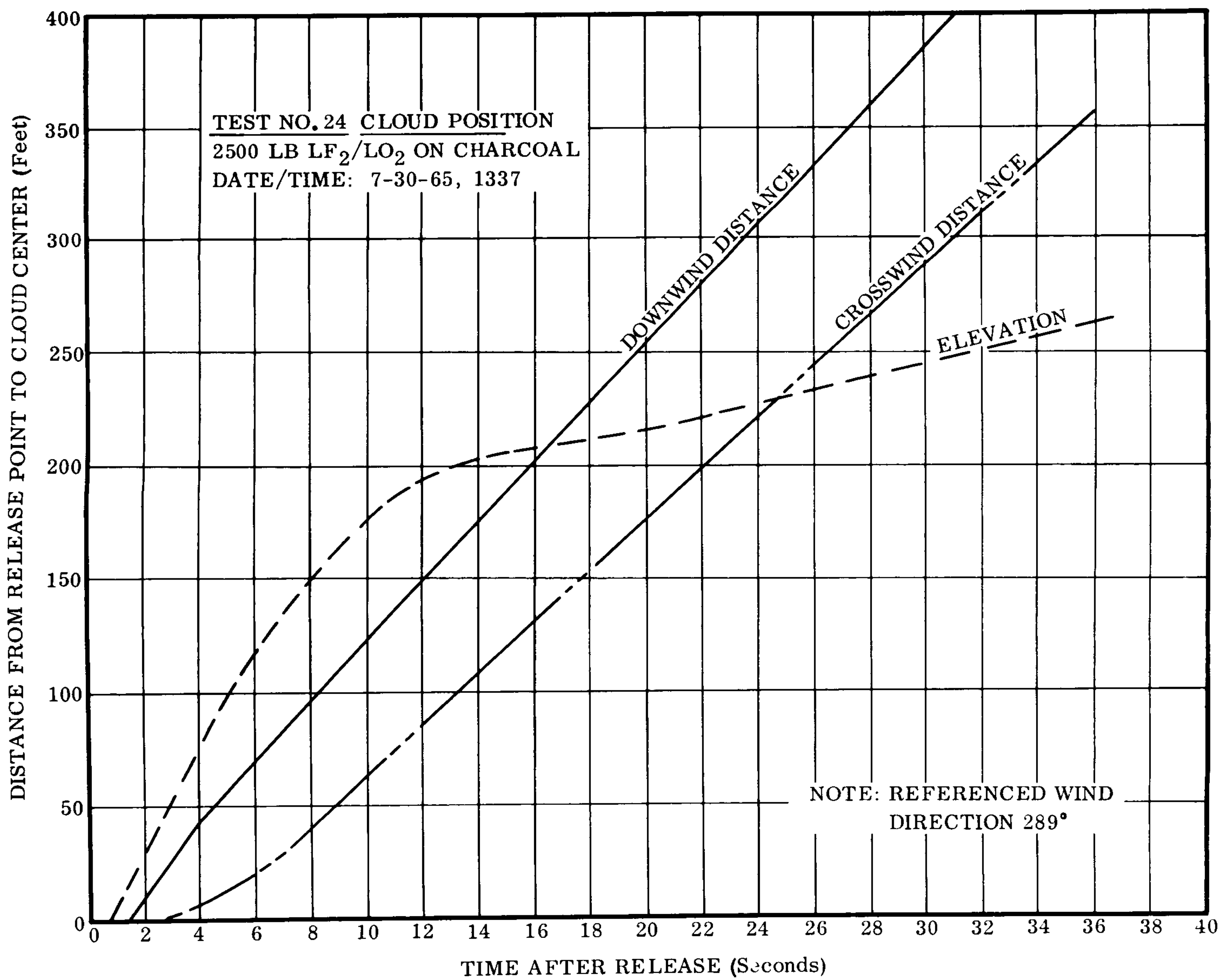


Figure 5-30. Test No. 24 Cloud Position

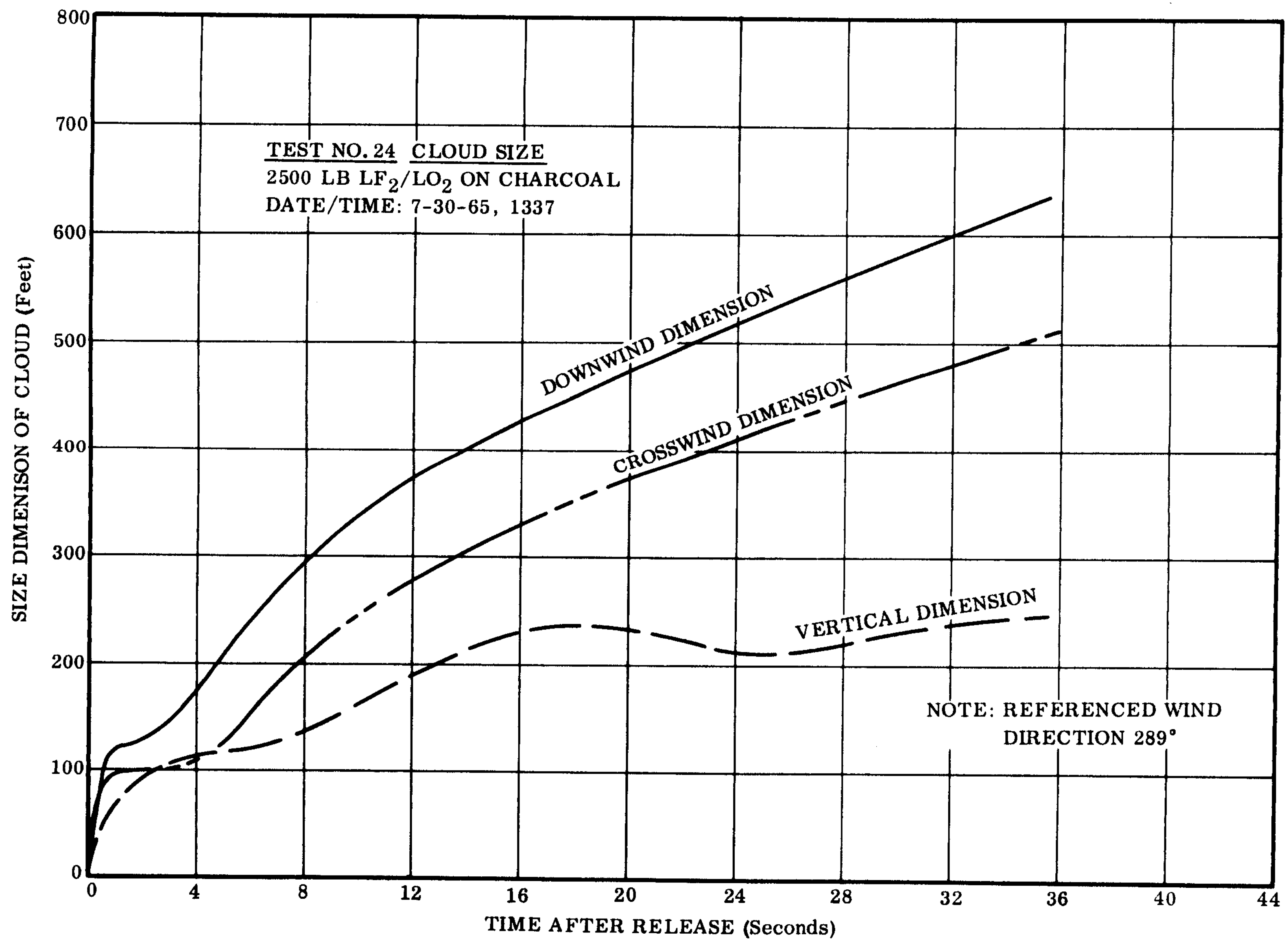


Figure 5-31. Test No. 24 Cloud Size

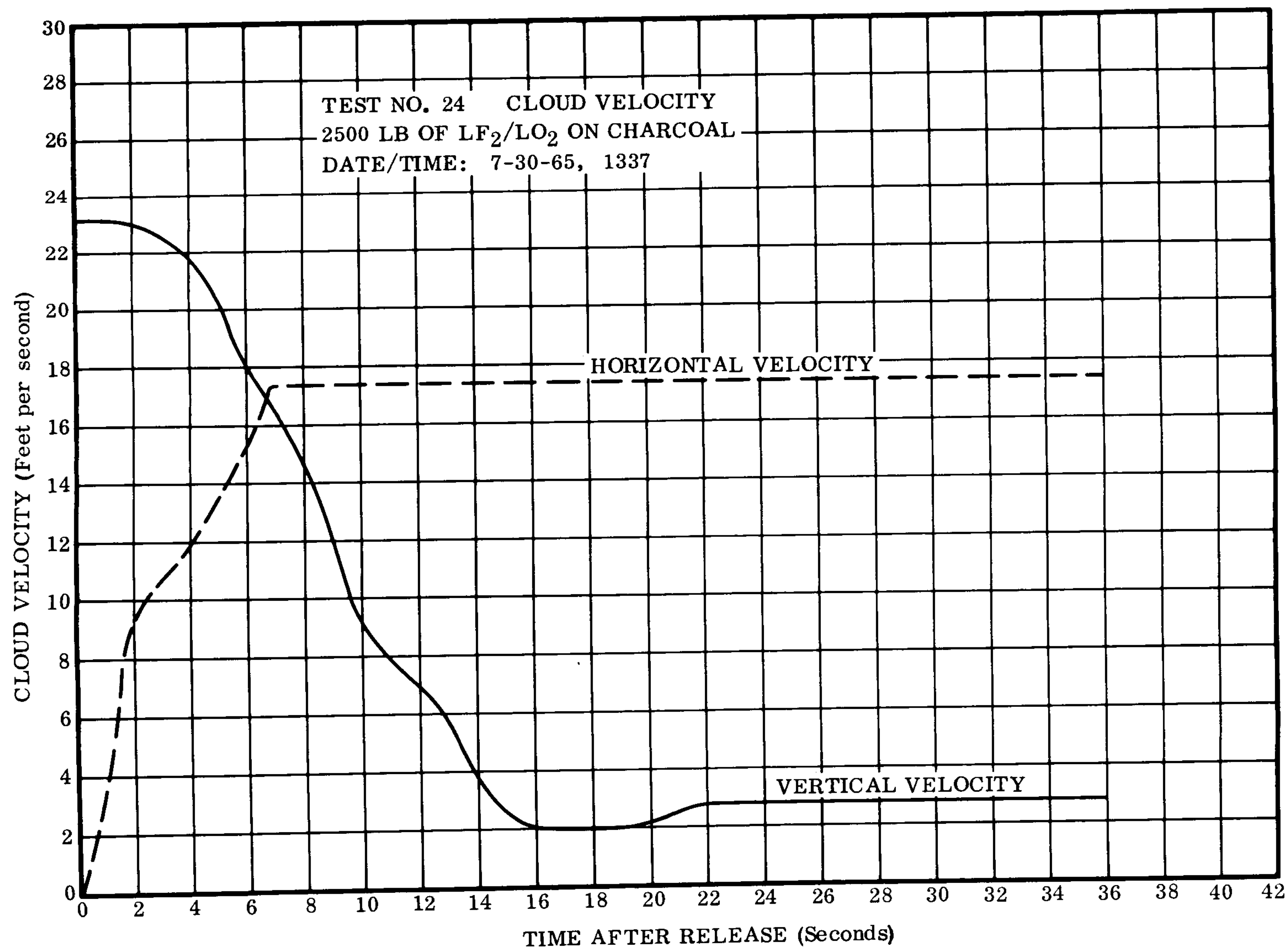


Figure 5-32. Test No. 24 Cloud Velocity

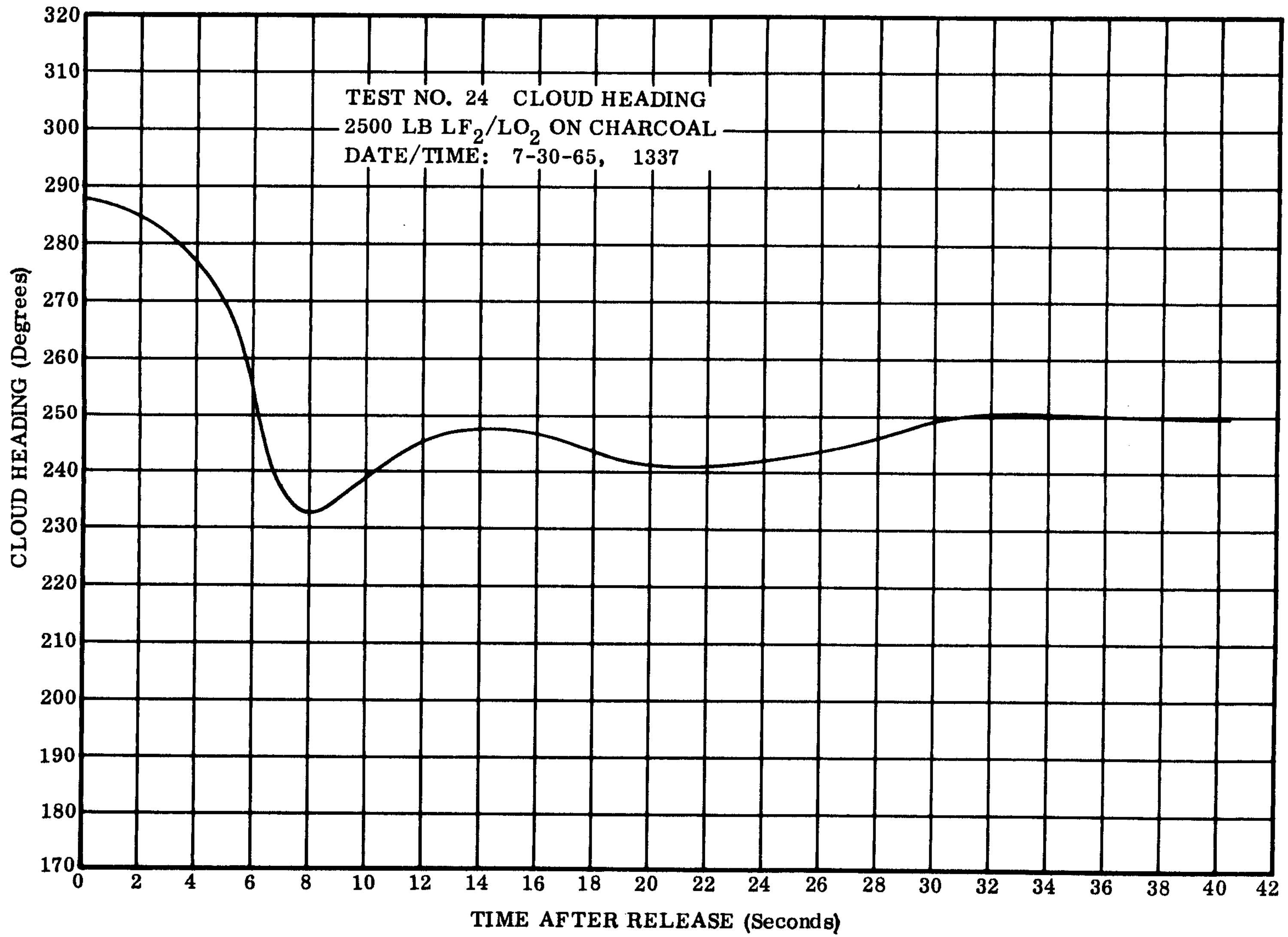


Figure 5-33. Test No. 24 Cloud Heading

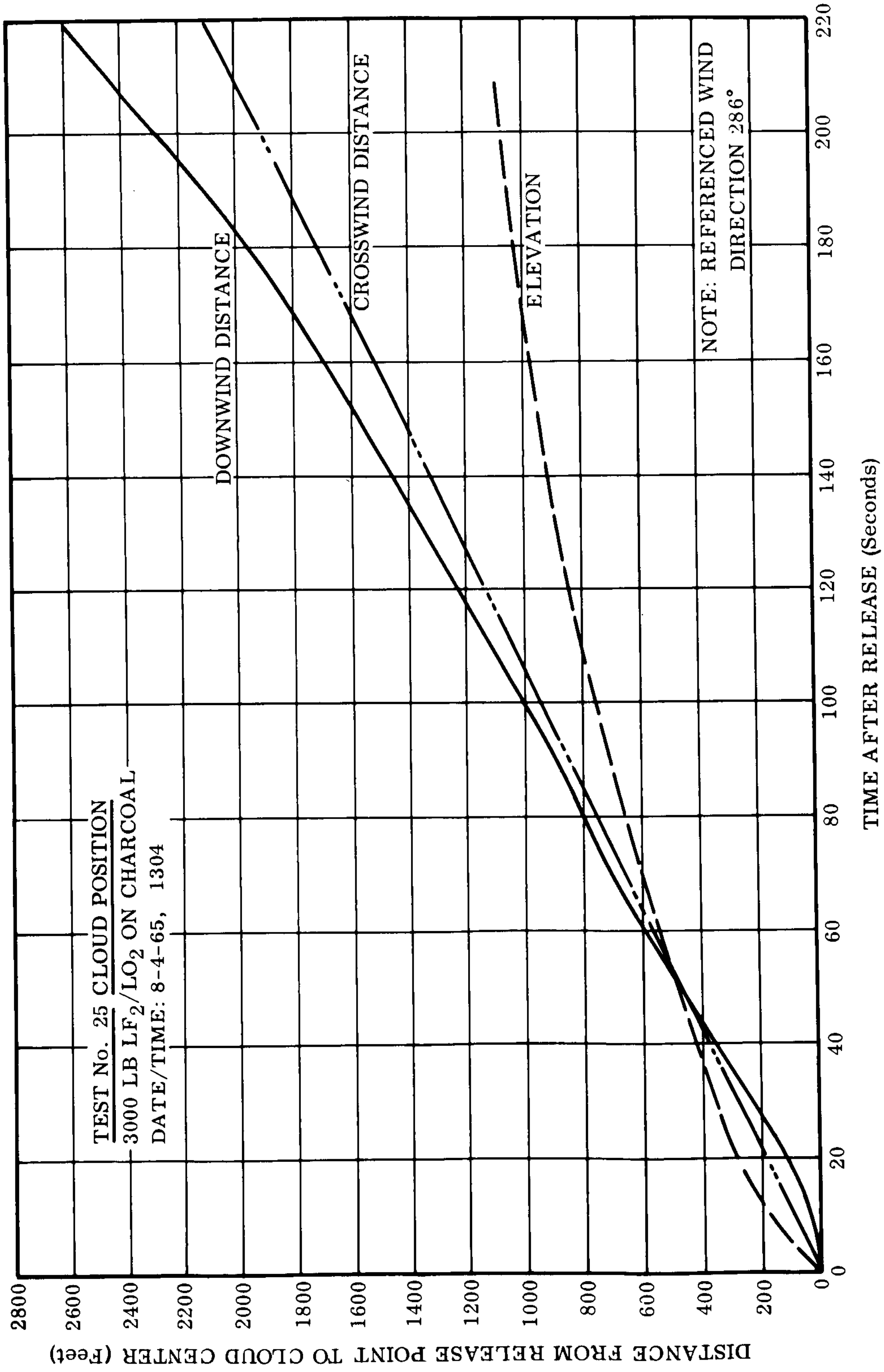


Figure 5-34. Test No. 25 Cloud Position

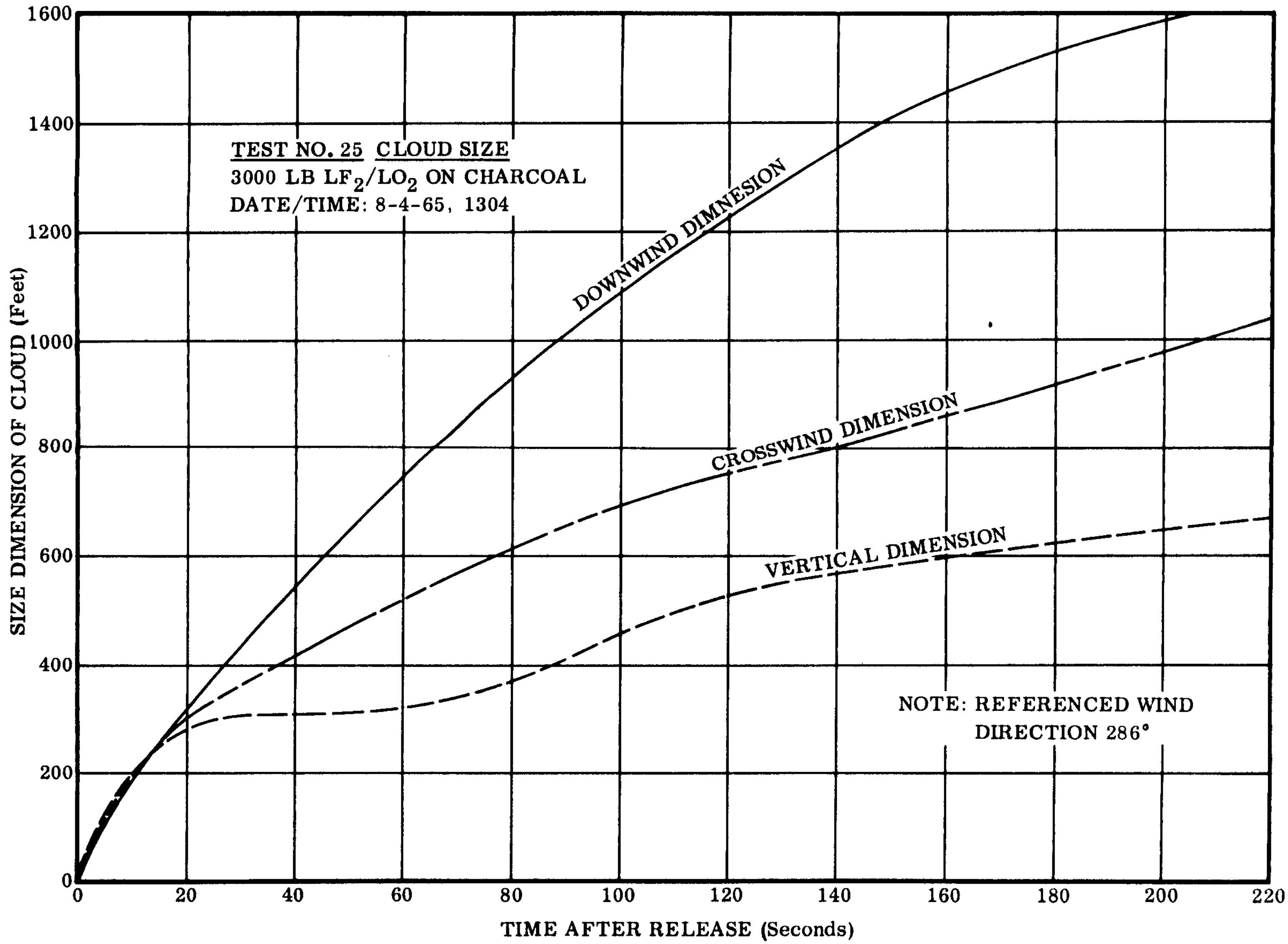


Figure 5-35. Test No. 25 Cloud Size

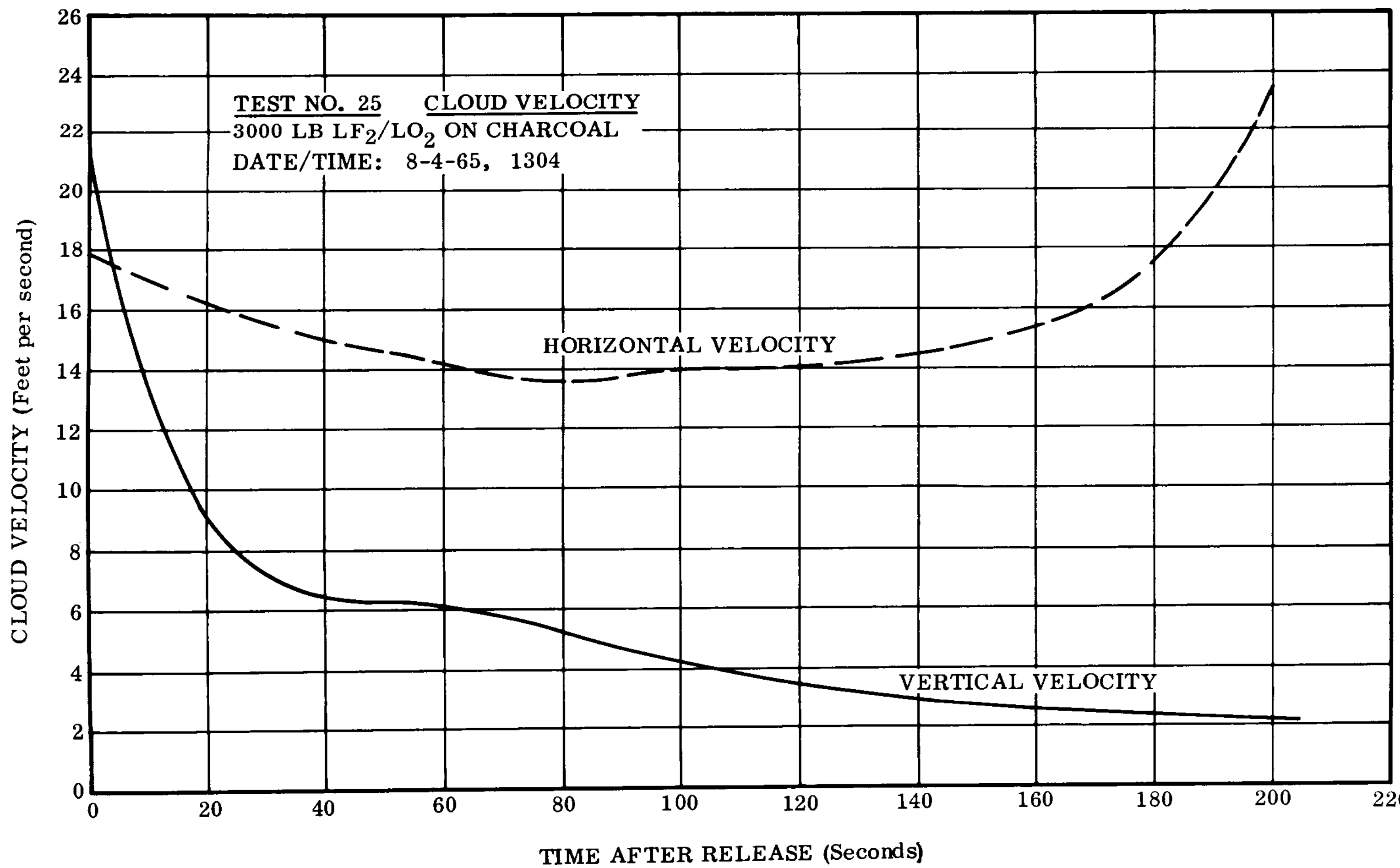


Figure 5-36. Test No. 25 Cloud Velocity

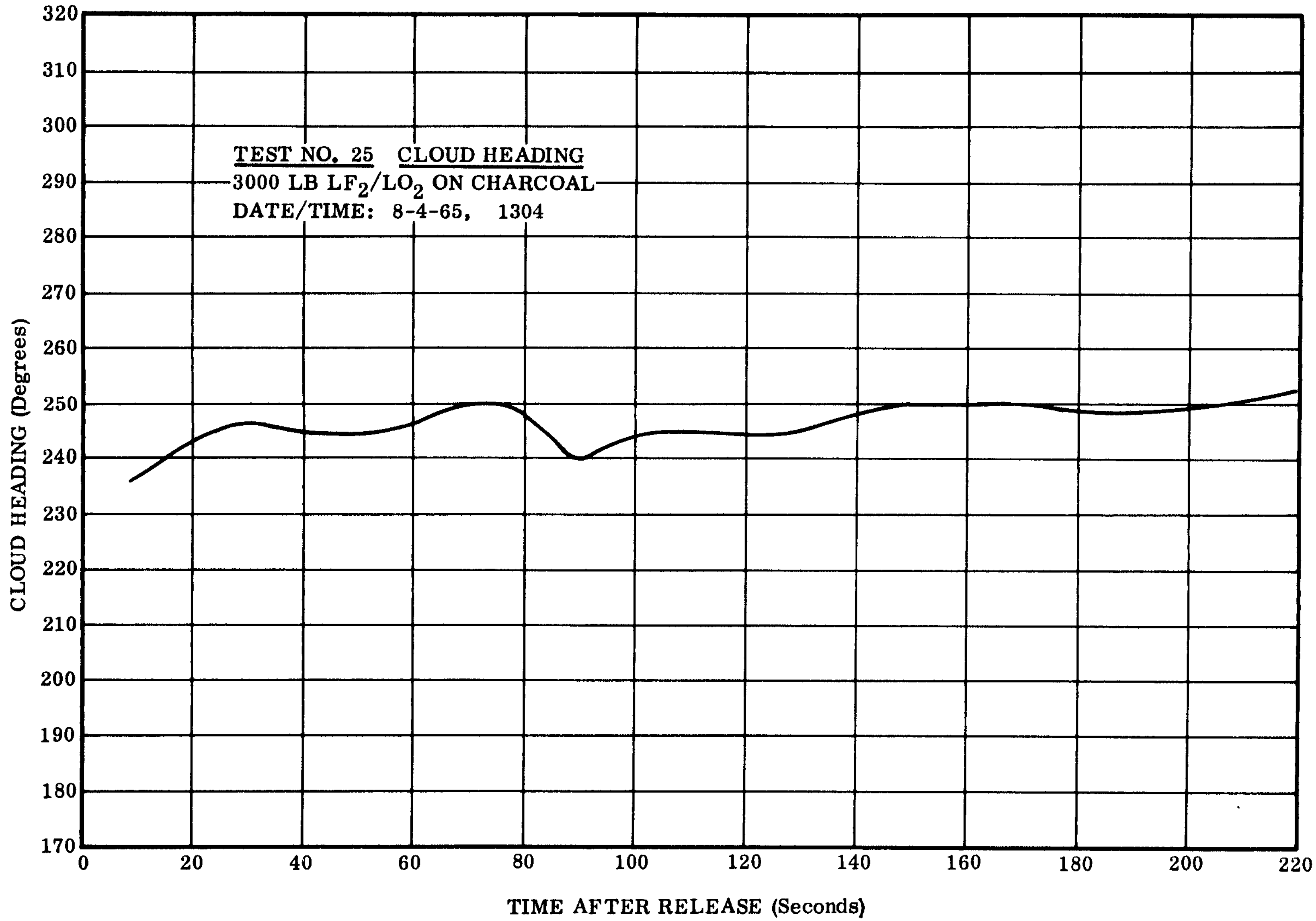


Figure 5-37. Test No. 25 Cloud Heading

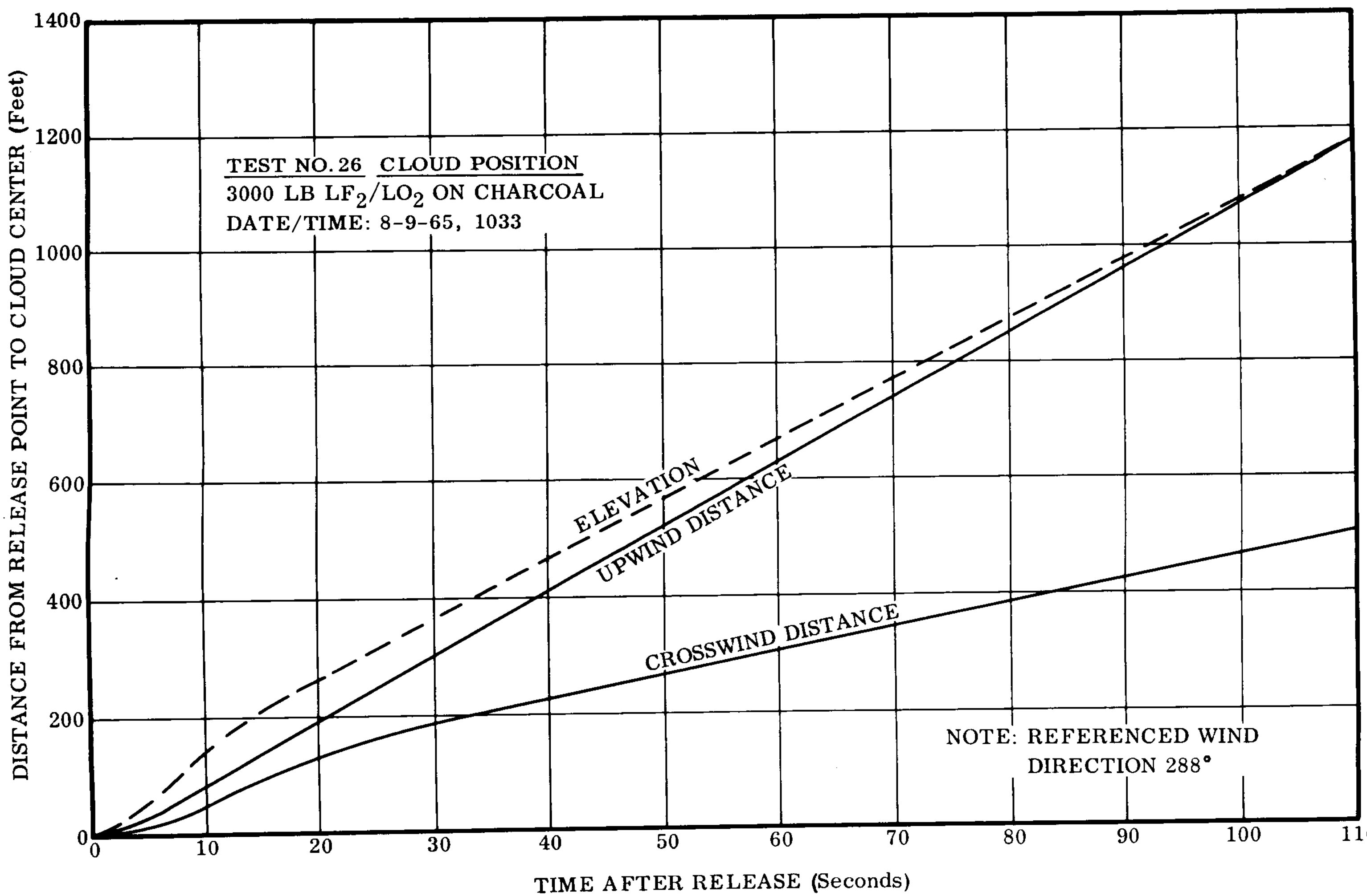


Figure 5-38. Test No. 26 Cloud Position

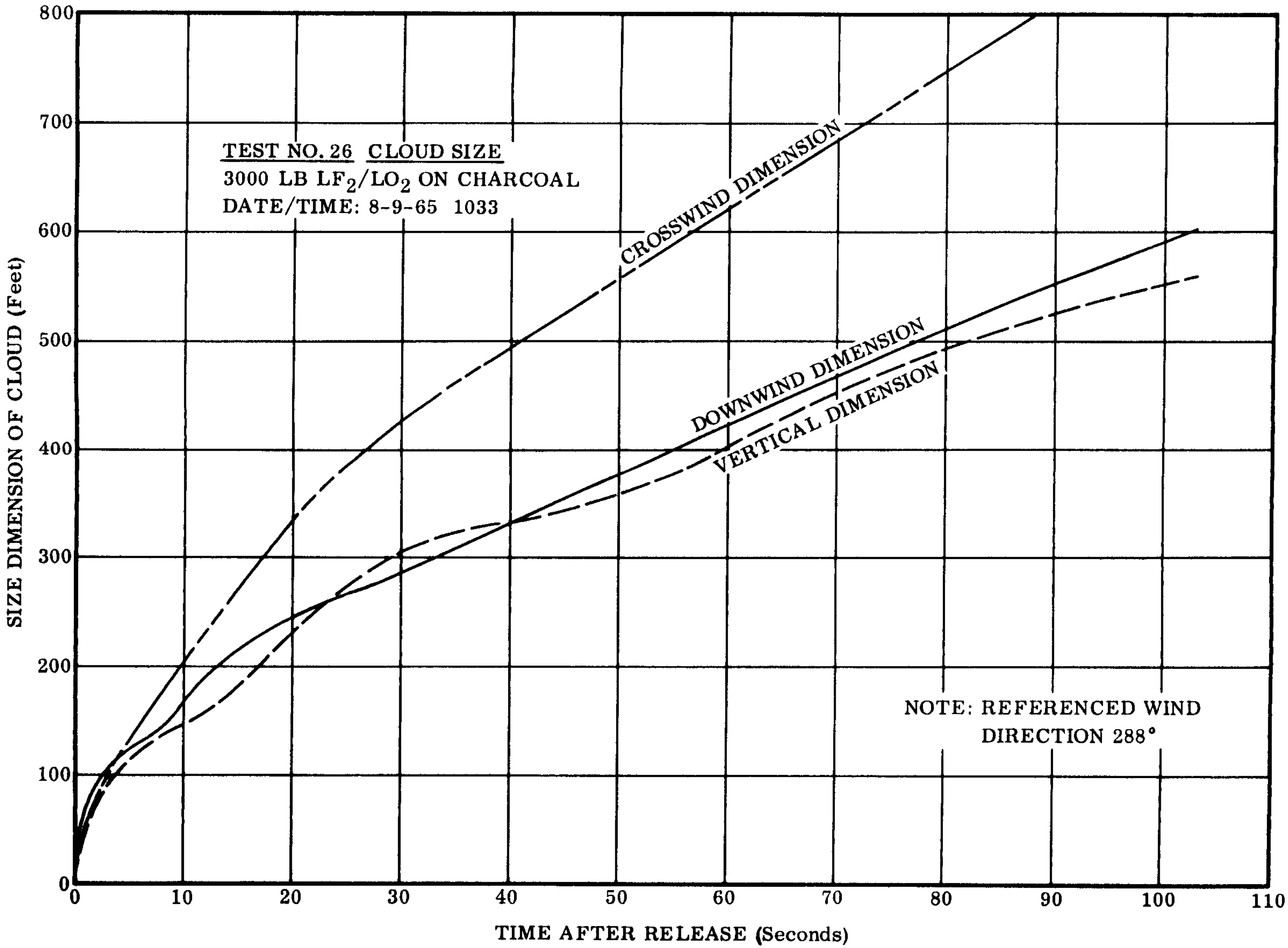


Figure 5-39. Test No. 26 Cloud Size

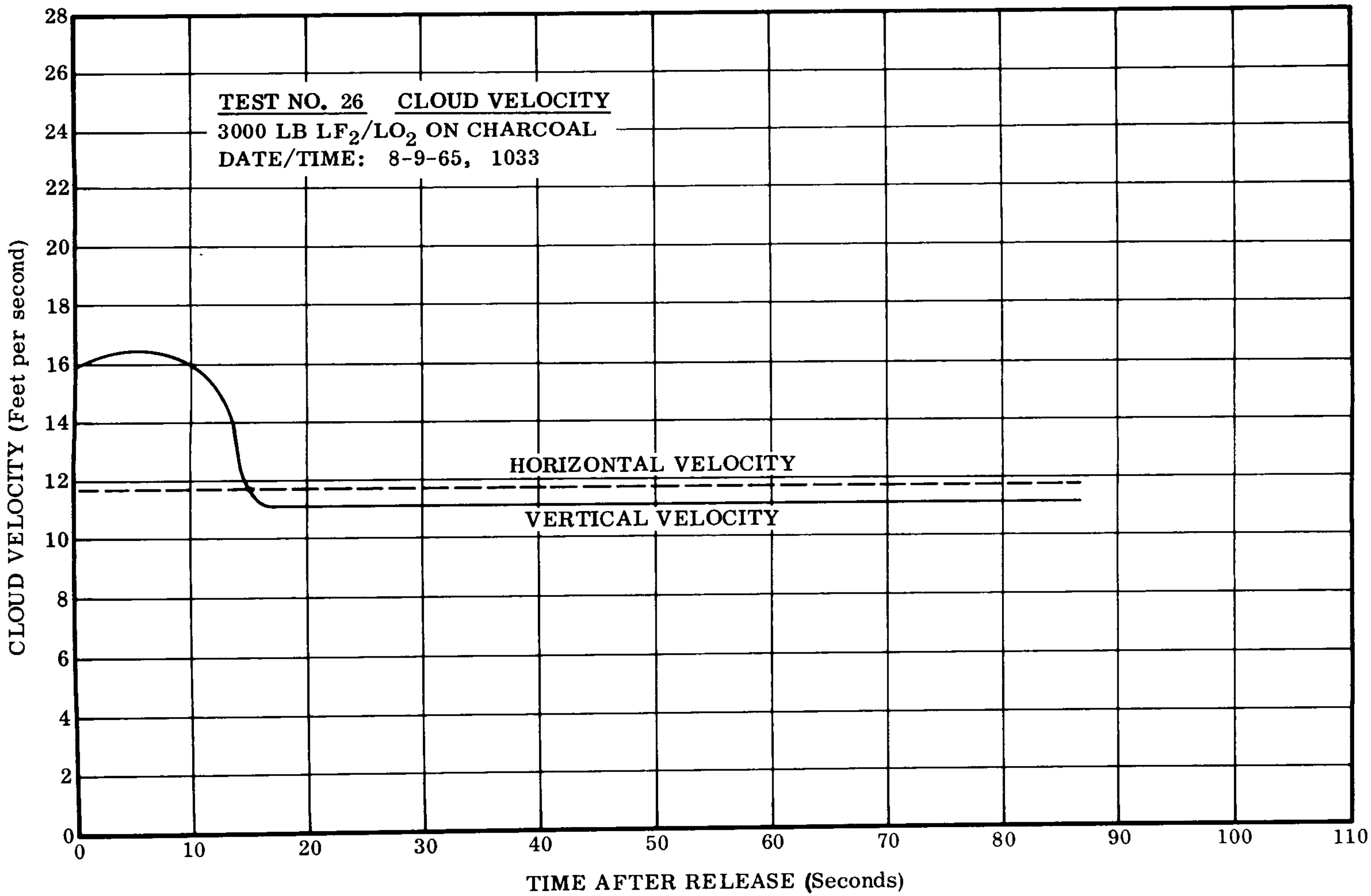


Figure 5-40. Test No. 26 Cloud Velocity

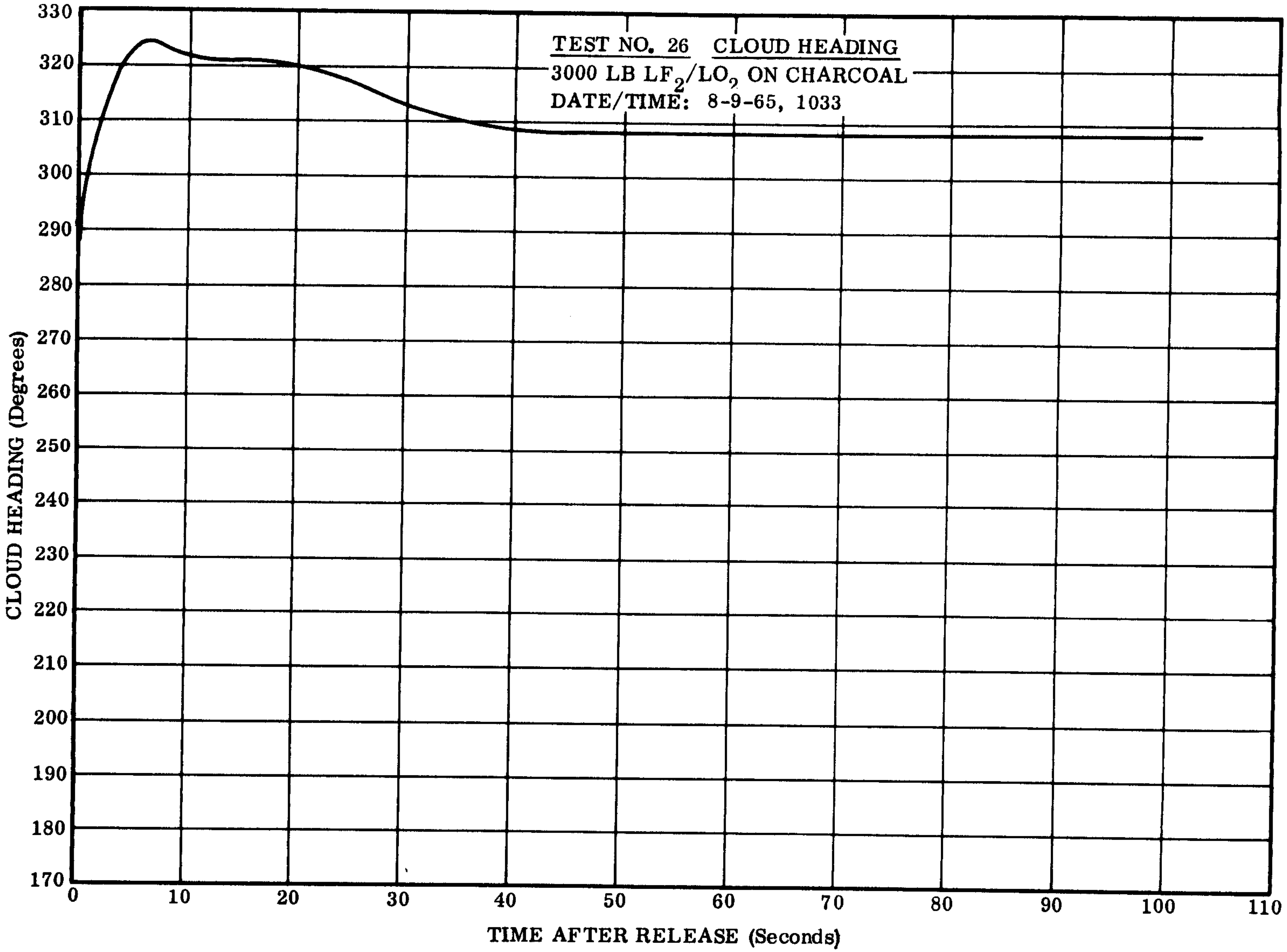


Figure 5-41. Test No. 26 Cloud Heading

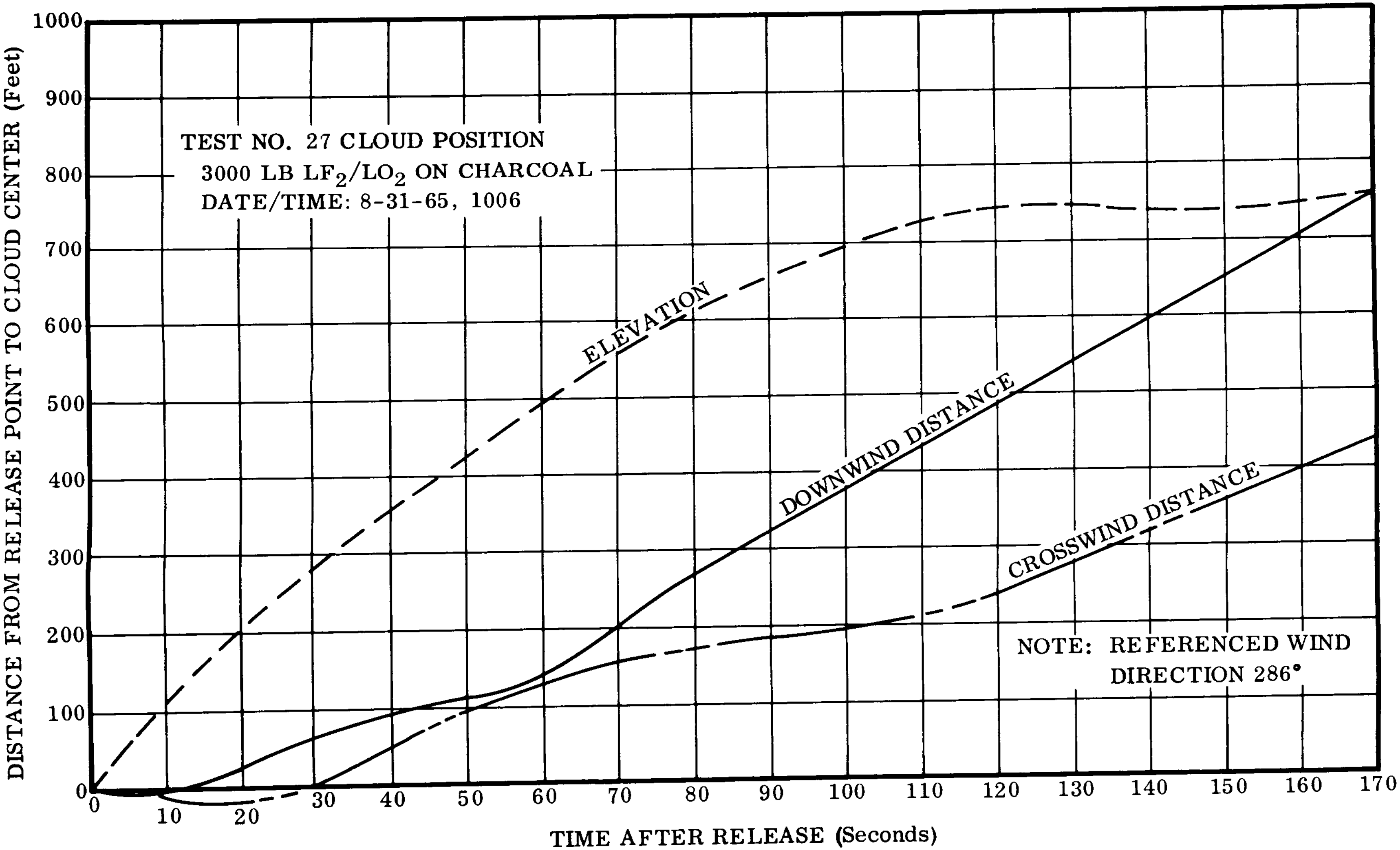


Figure 5-42. Test No. 27 Cloud Position

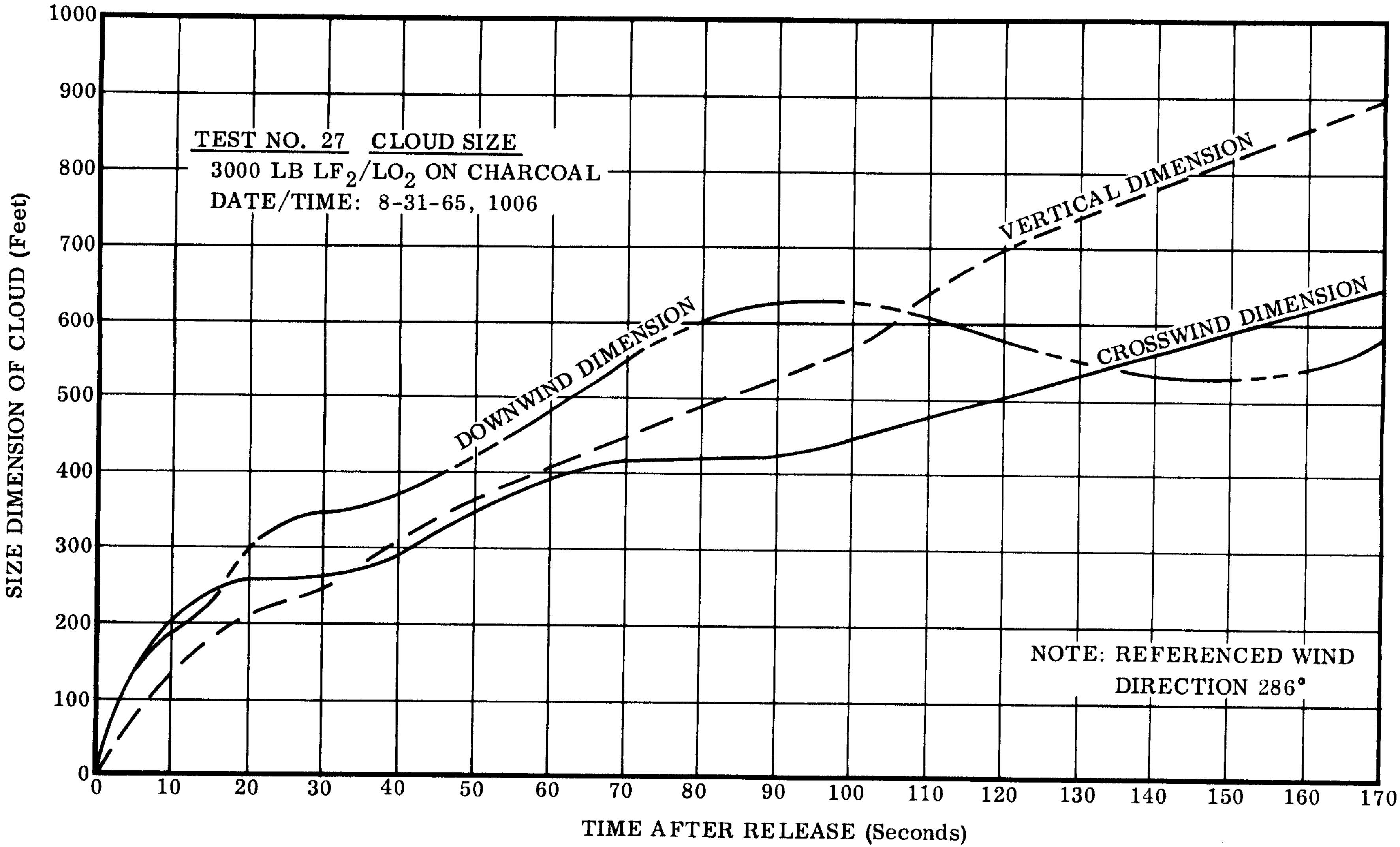


Figure 5-43. Test No. 27 Cloud Size

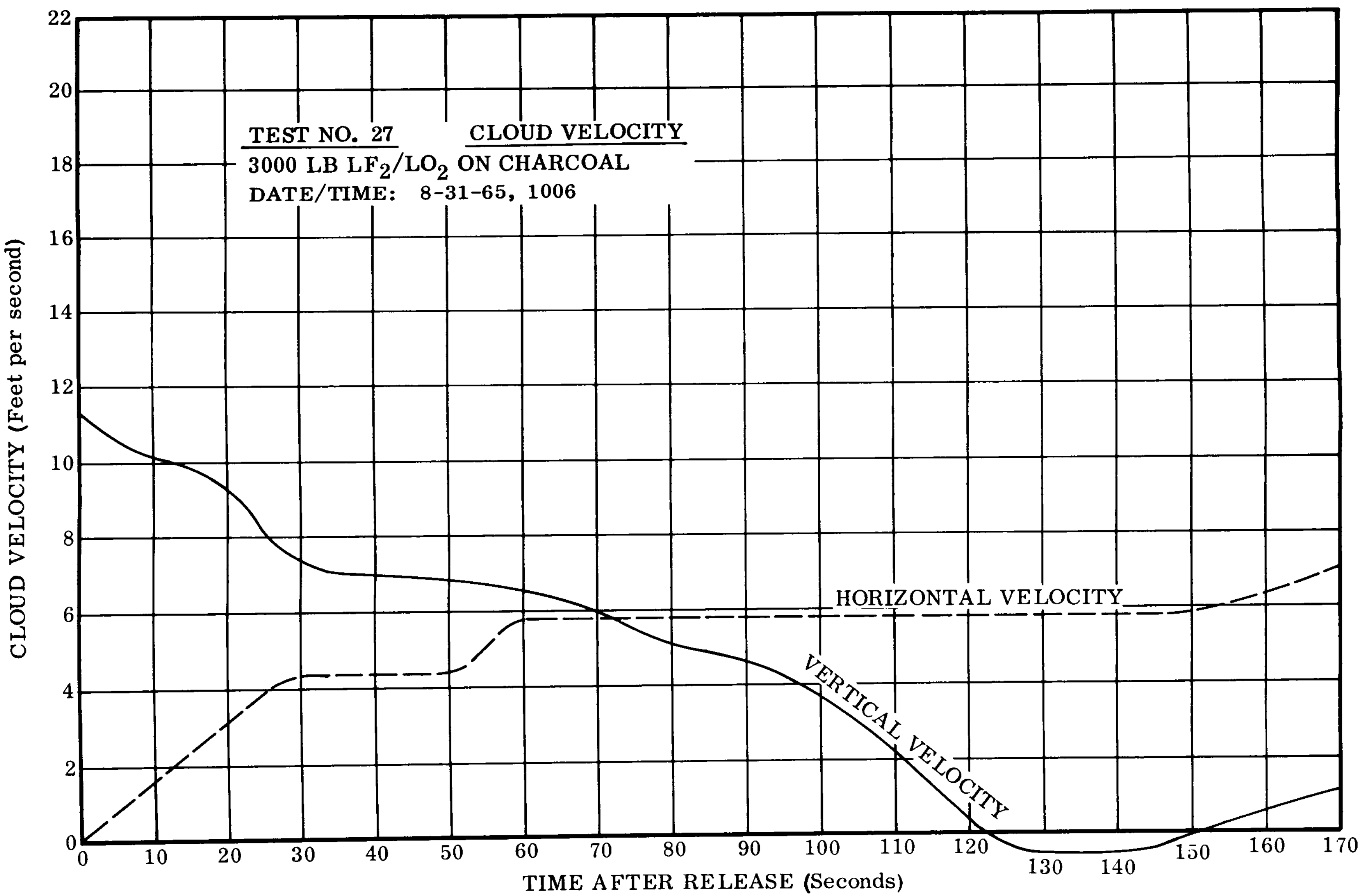


Figure 5-44. Test No. 27 Cloud Velocity

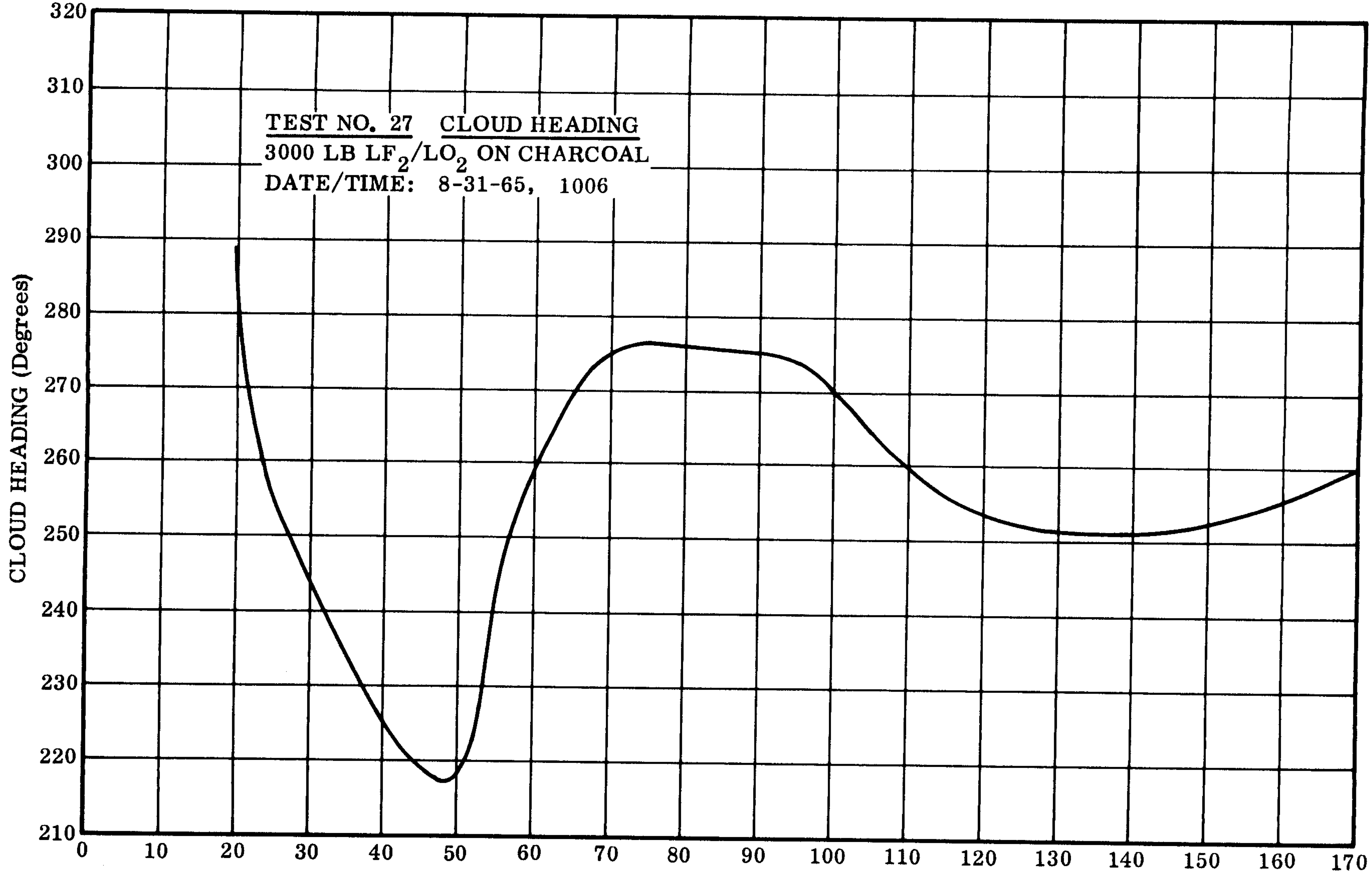


Figure 5-45. Test No. 27 Cloud Heading

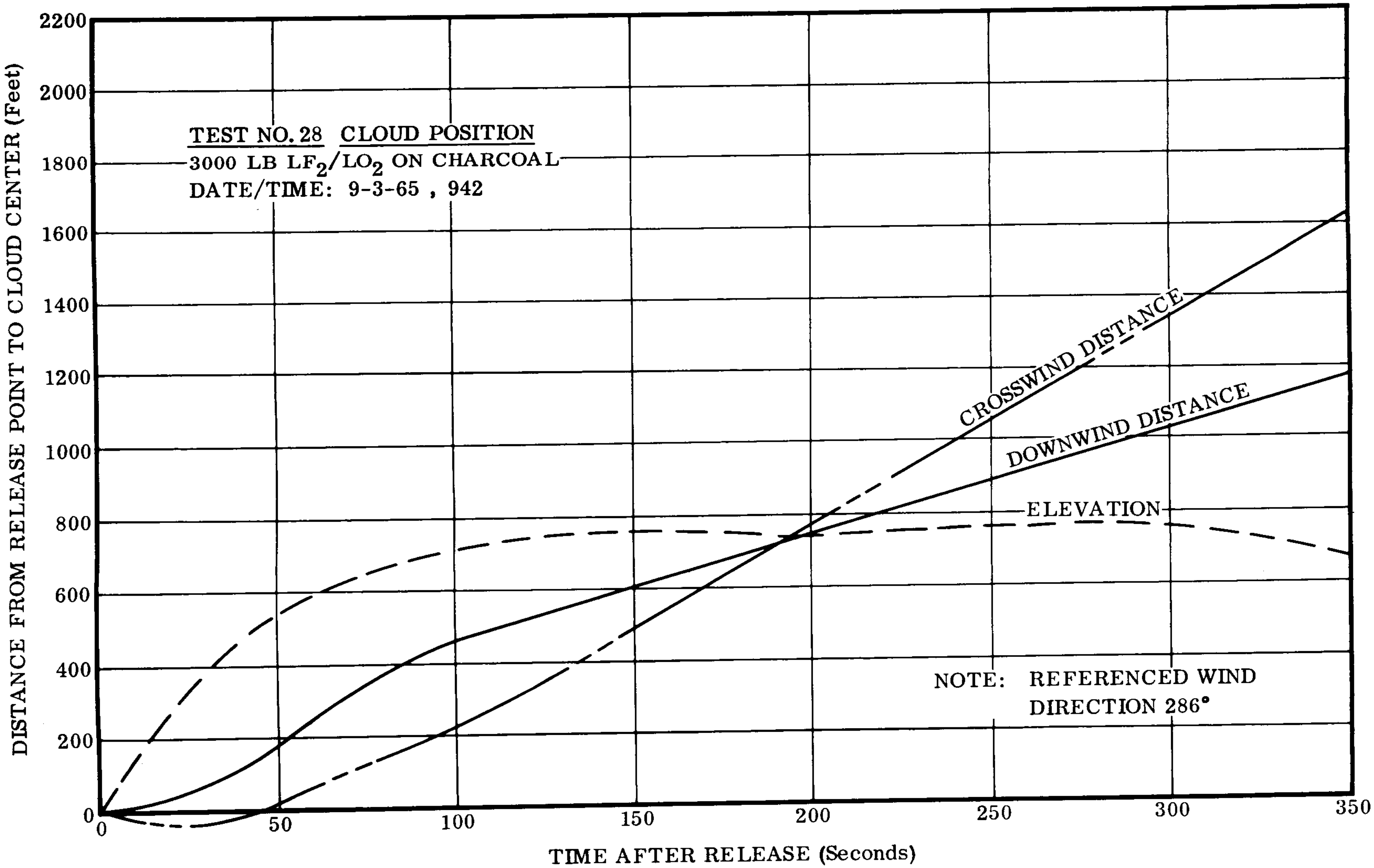


Figure 5-46. Test No. 28 Cloud Position

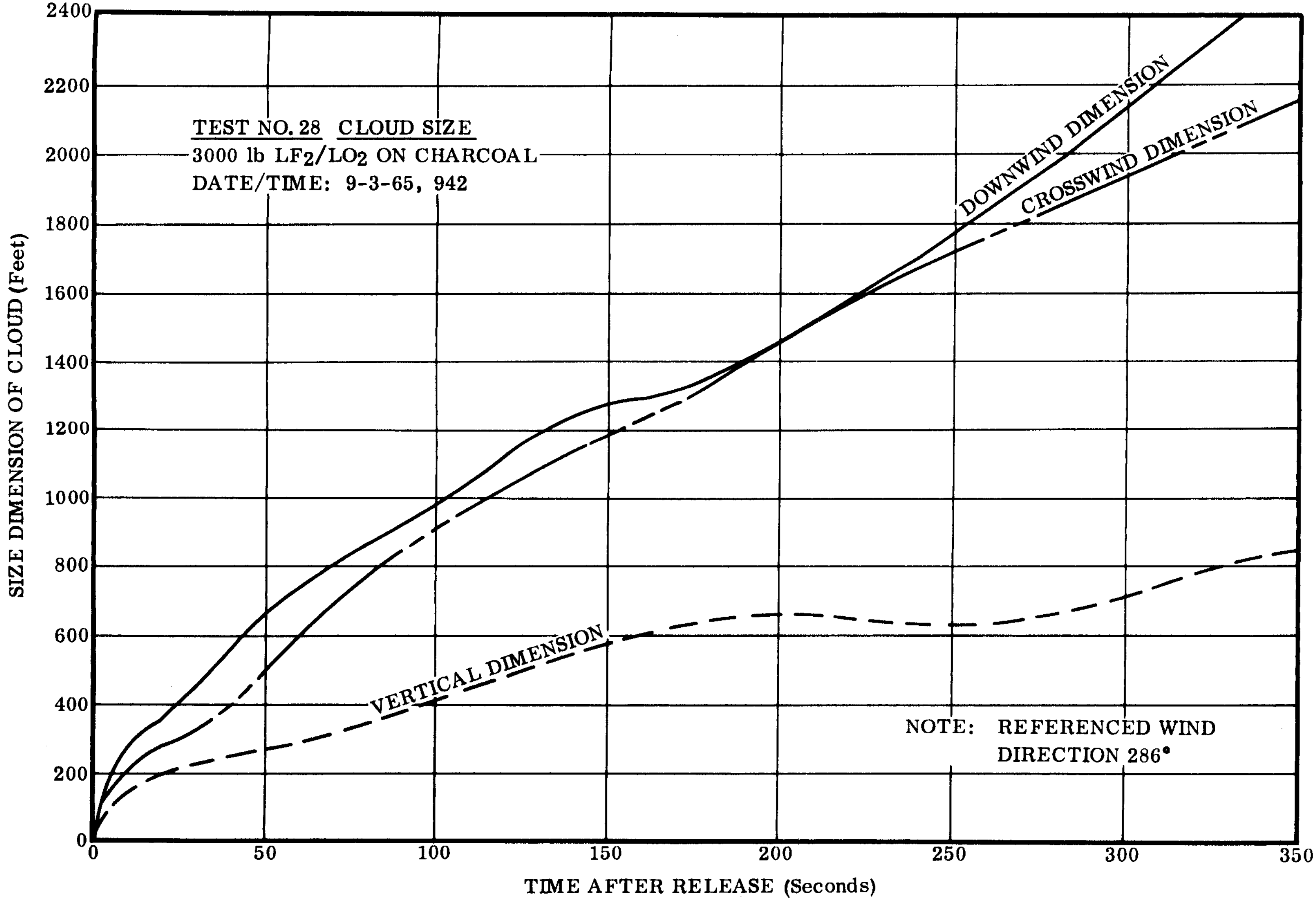


Figure 5-47. Test No. 28 Cloud Size

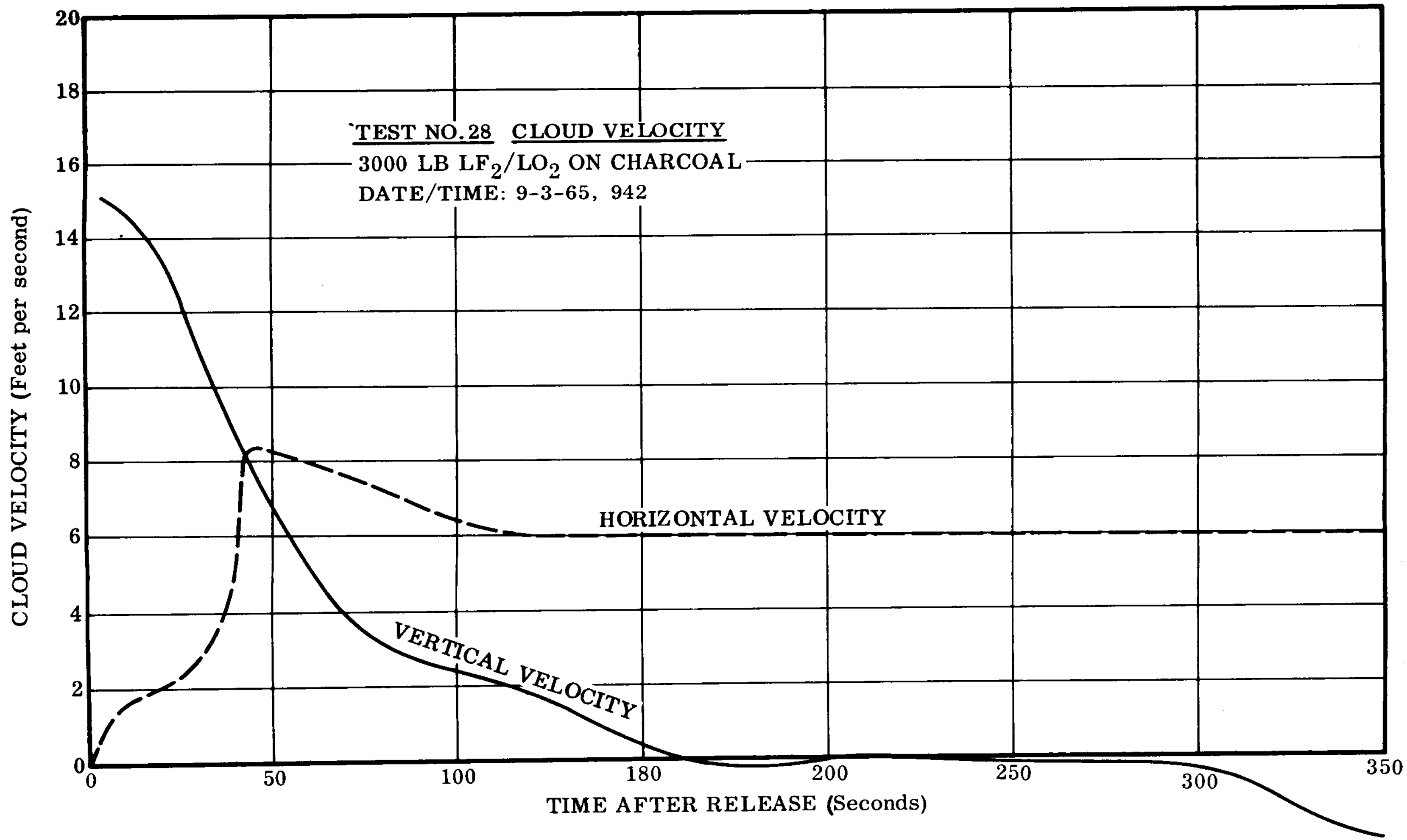


Figure 5-48. Test No. 28 Cloud Velocity

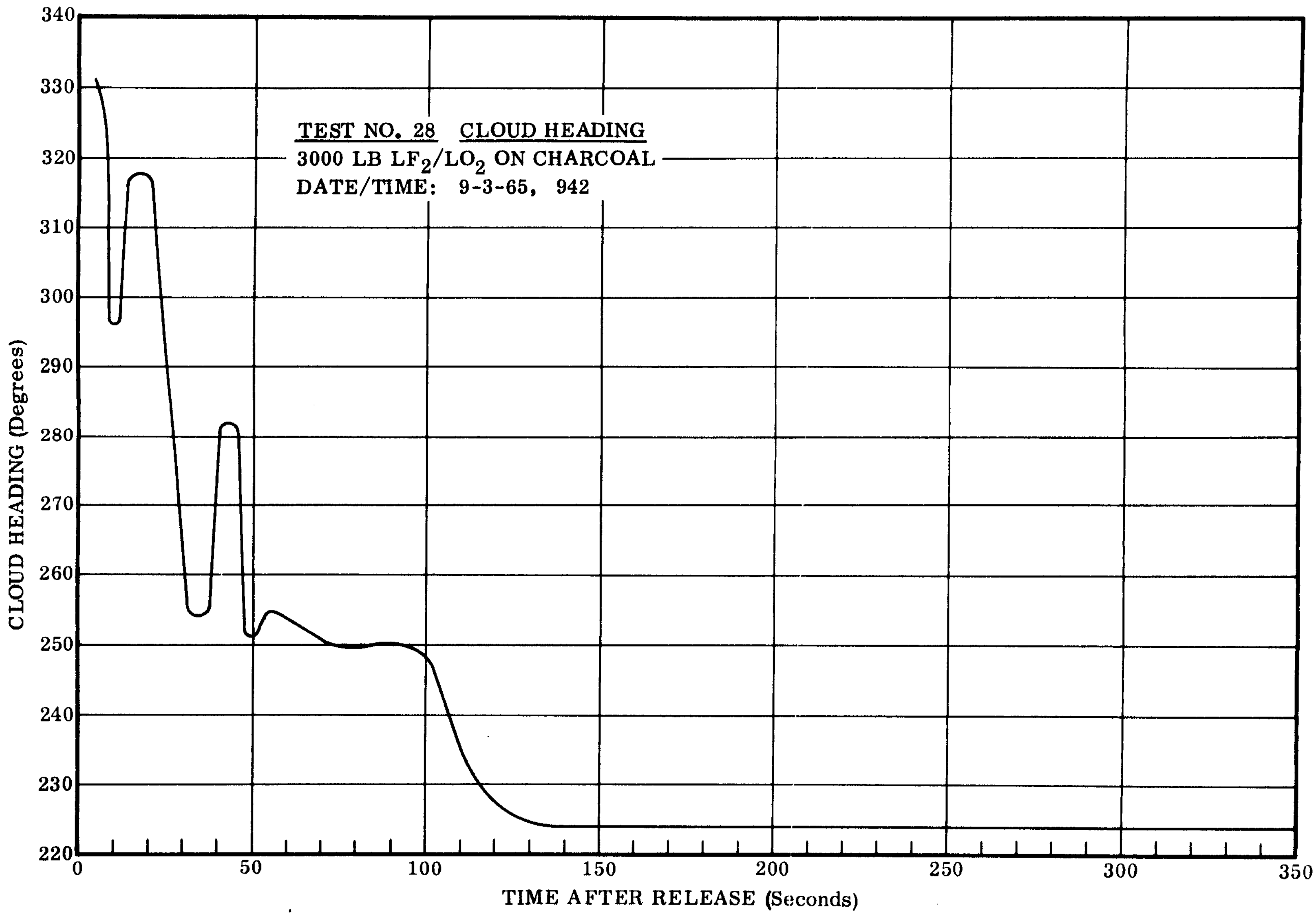


Figure 5-49. Test No. 28 Cloud Heading

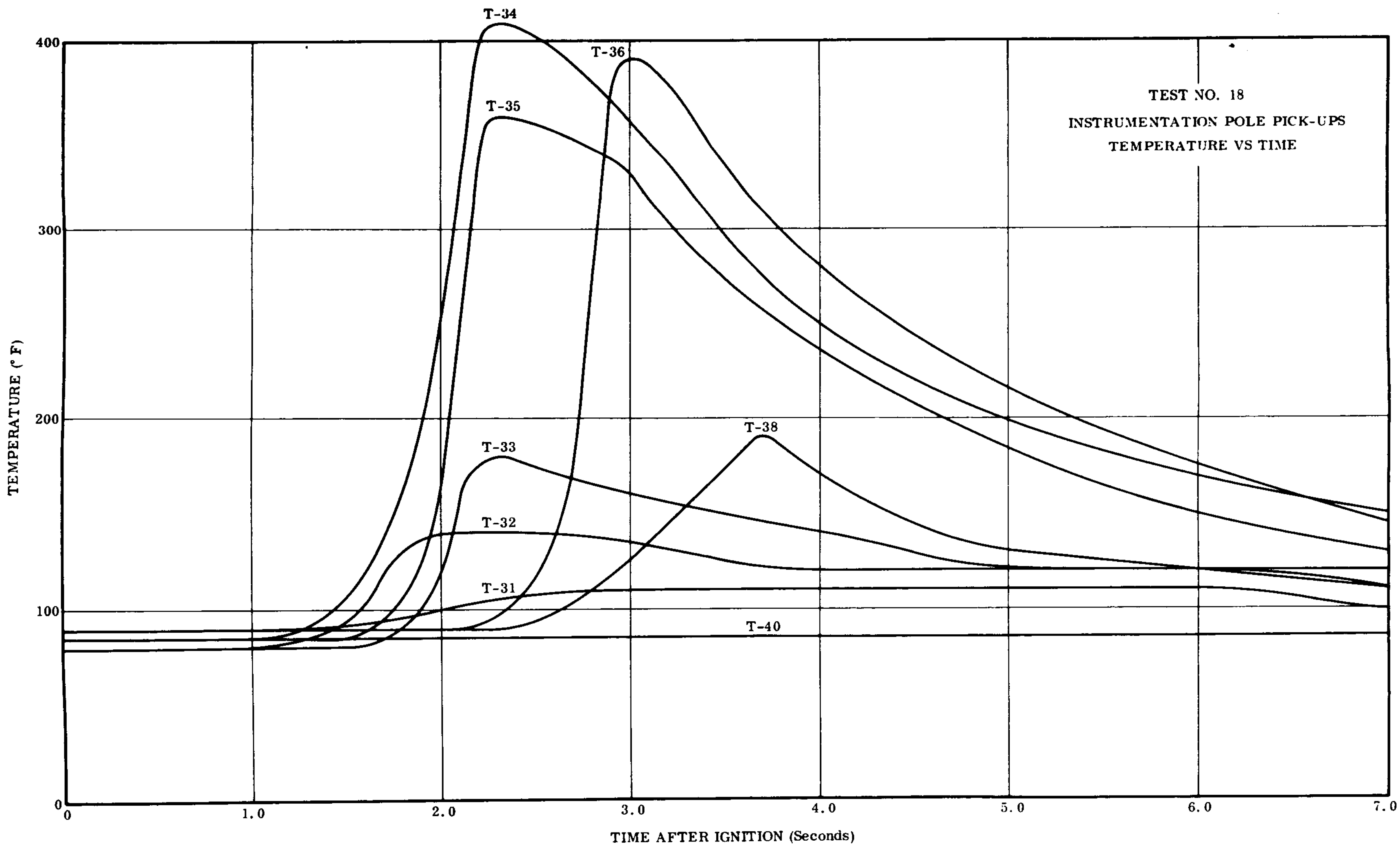


Figure 5-50. Test No. 18 Instrumentation Pole Pick-Ups

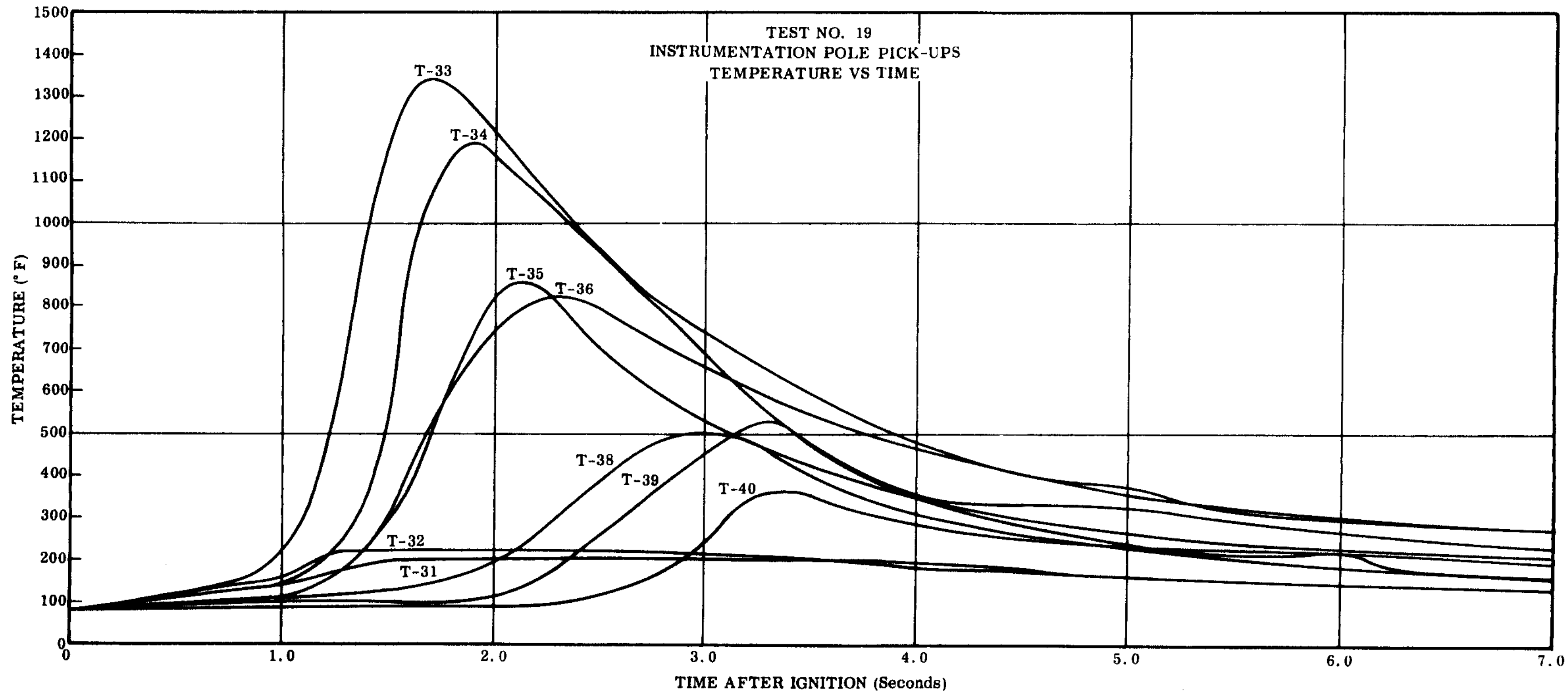


Figure 5-51. Test No. 19 Instrumentation Pole Pick-Ups

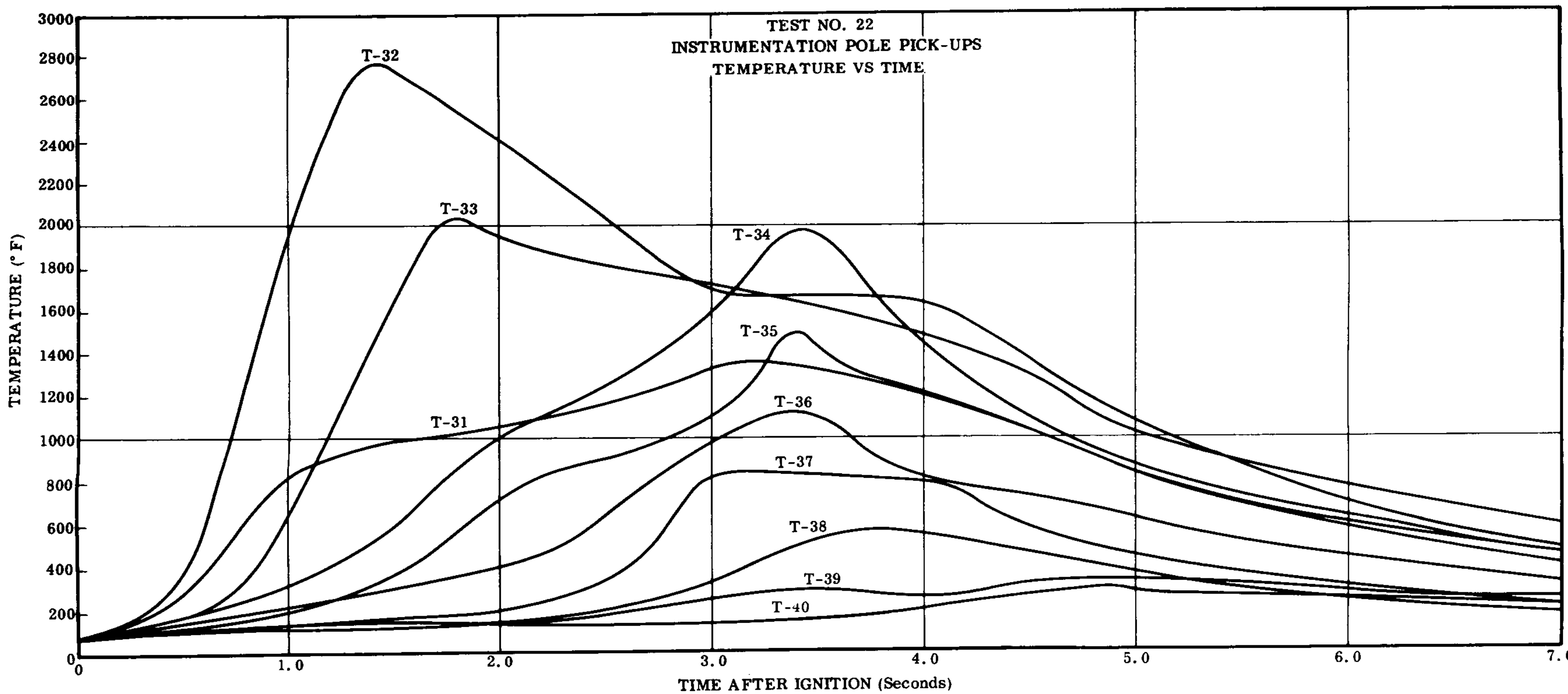


Figure 5-52. Test No. 22 Instrumentation Pole Pick-Ups

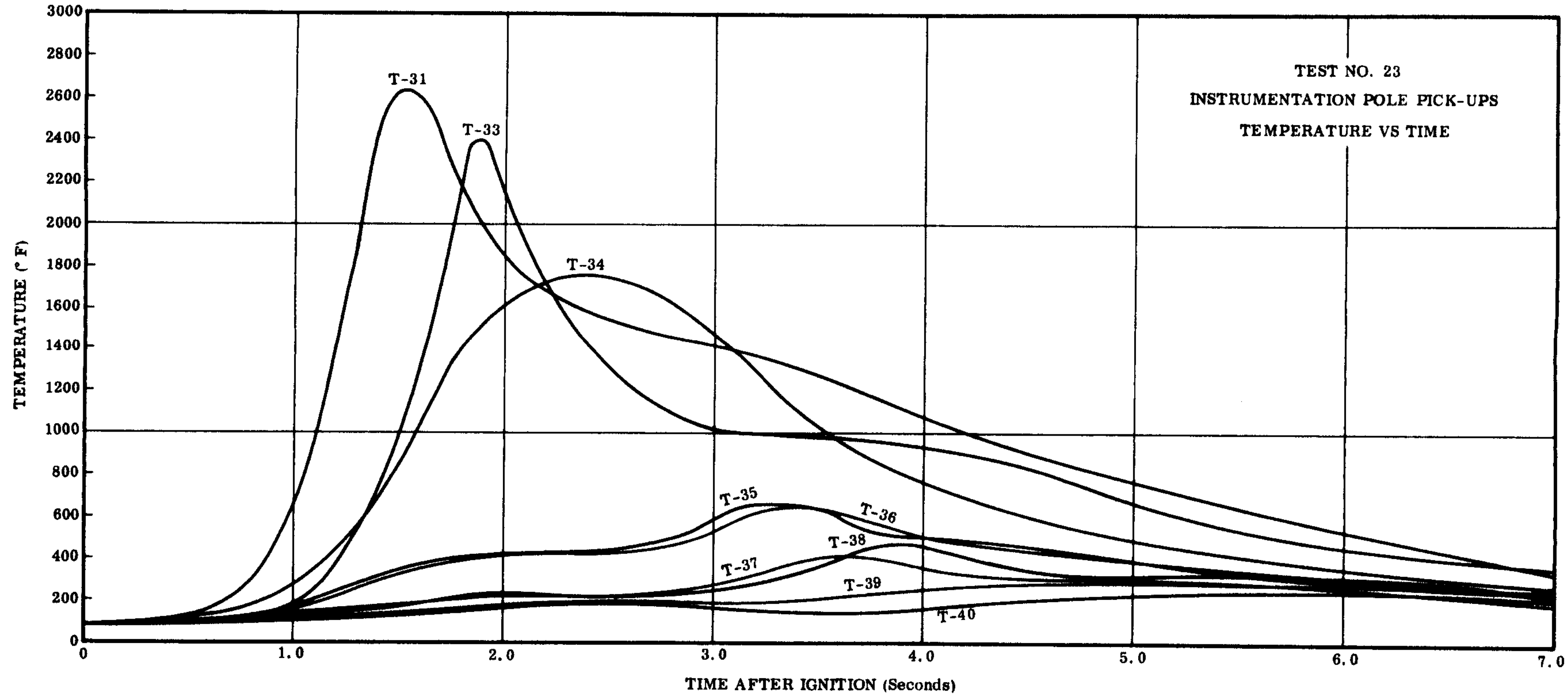


Figure 5-53. Test No. 23 Instrumentation Pole Pick-Ups

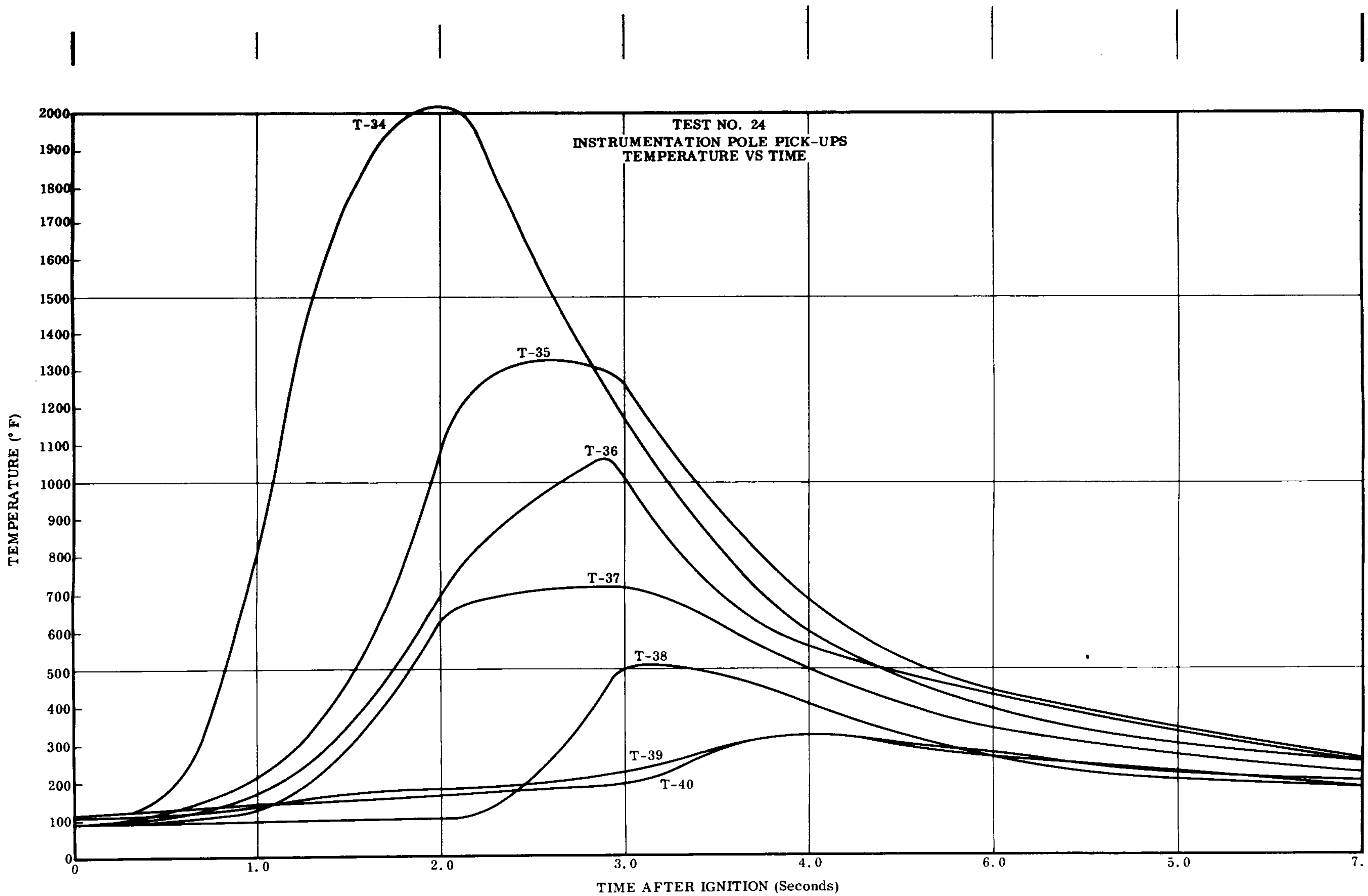


Figure 5-54. Test No. 24 Instrumentation Pole Pick-Ups

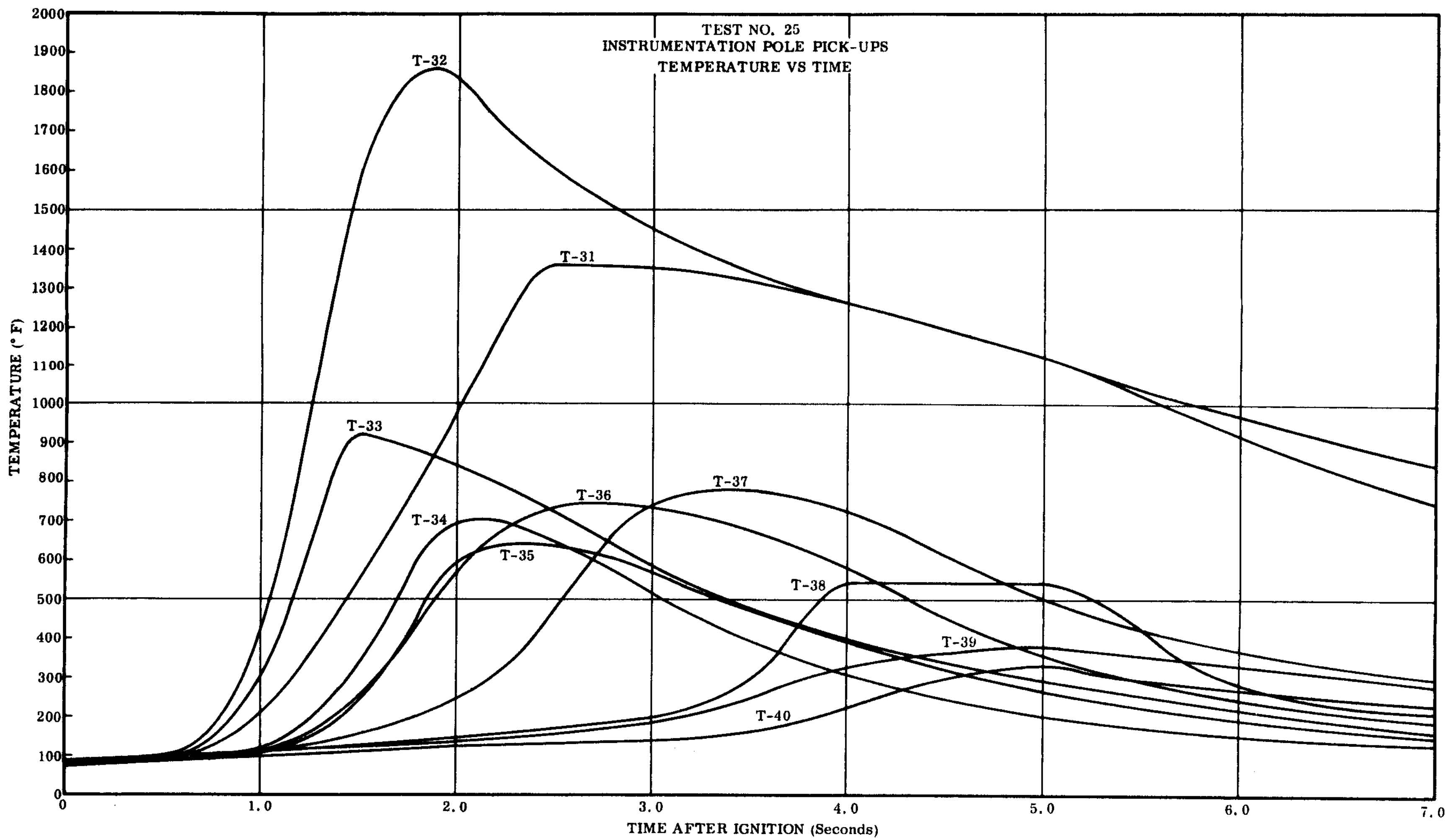


Figure 5-55. Test No. 25 Instrumentation Pole Pick-Ups

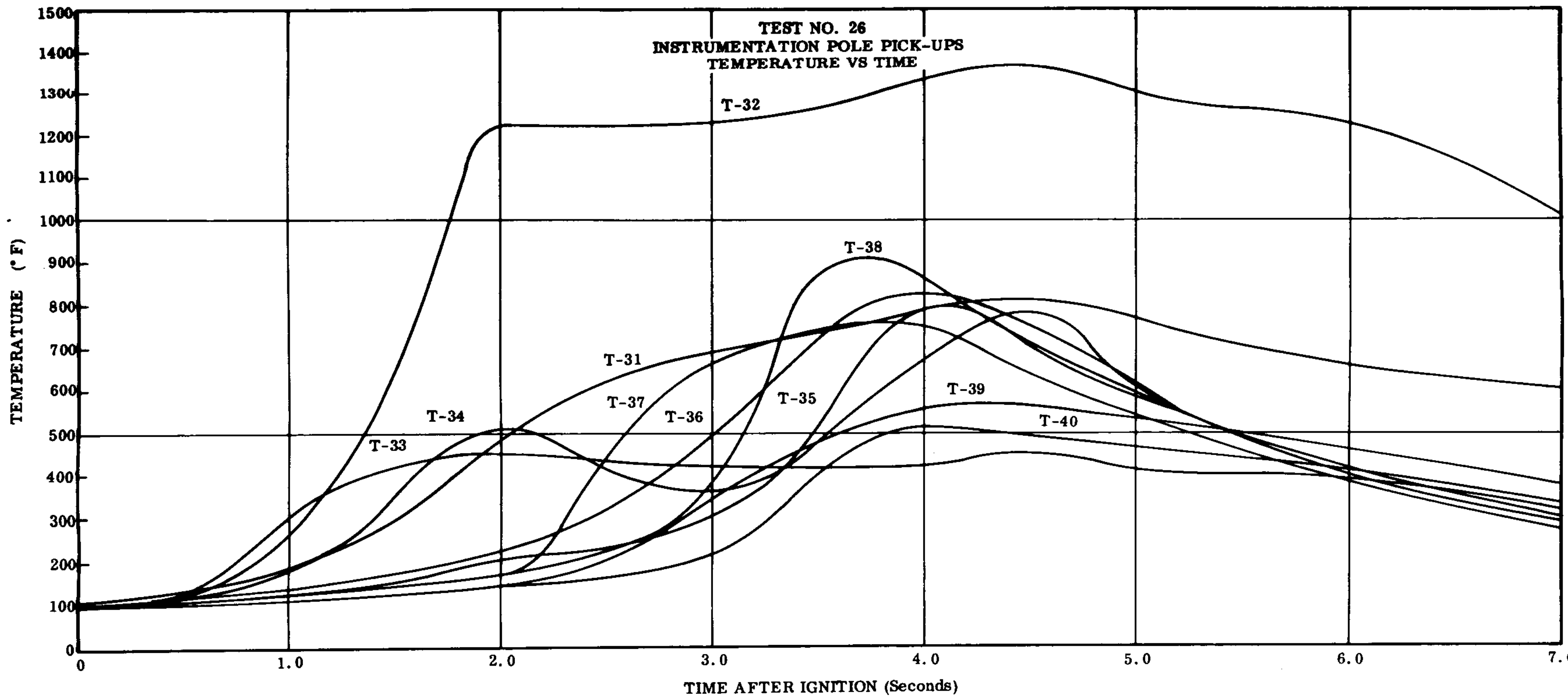


Figure 5-56. Test No. 26 Instrumentation Pole Pick-Ups

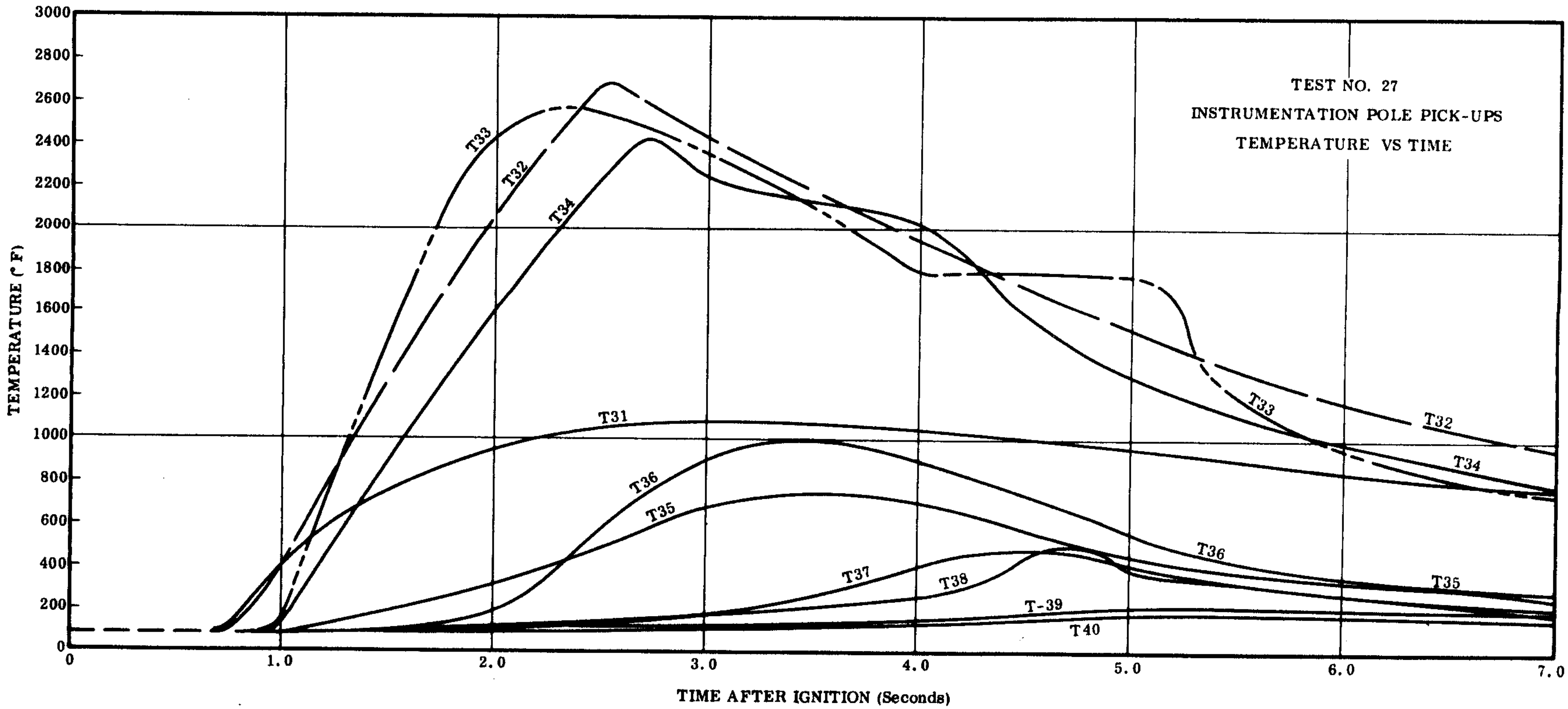


Figure 5-57. Test No. 27 Instrumentation Pole Pick-Ups

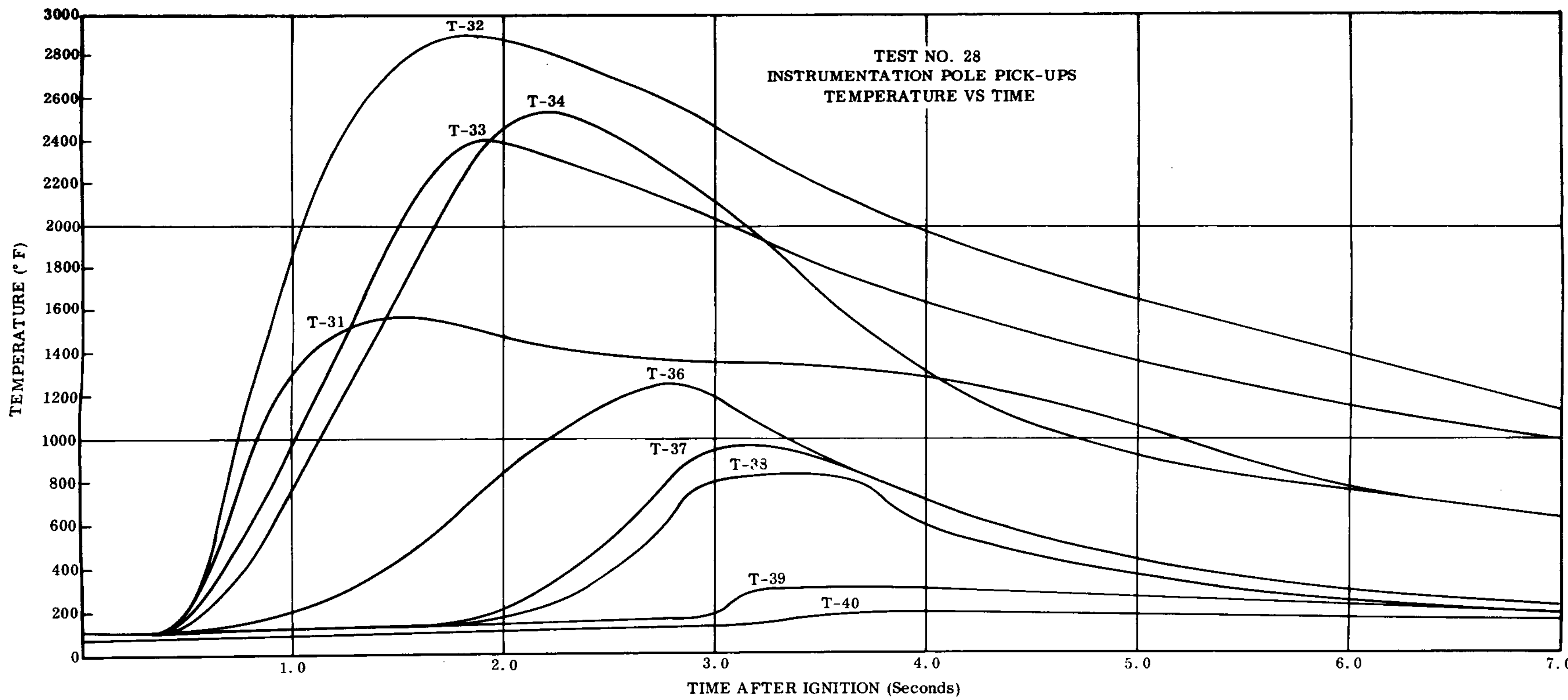


Figure 5-58. Test No. 28 Instrumentation Pole Pick-Ups

was effective and a good cloud was produced; the measured temperatures were quite low, indicating that only the outer portion of the cloud touched the thermocouples on the instrumentation pole. Subsequent tests, in which larger quantities of LF_2/LO_2 were employed, produced larger fireballs, and much higher temperatures were recorded. Figure 5-59 illustrates the hot cloud development during one of the 3000-lb LF_2/LO_2 spills (test 27).

Temperature vs time for each thermocouple is plotted in Figure 5-57. Time zero was taken as the time of ignition of the shaped charge that cut the bottom of the test tank. A short period of time then elapsed before the oxidizer fell and contacted the charcoal. The hypergolic reaction then proceeded as the liquid spread out. A further delay was noted before the fireball expanded and a temperature rise was recorded at the pole.

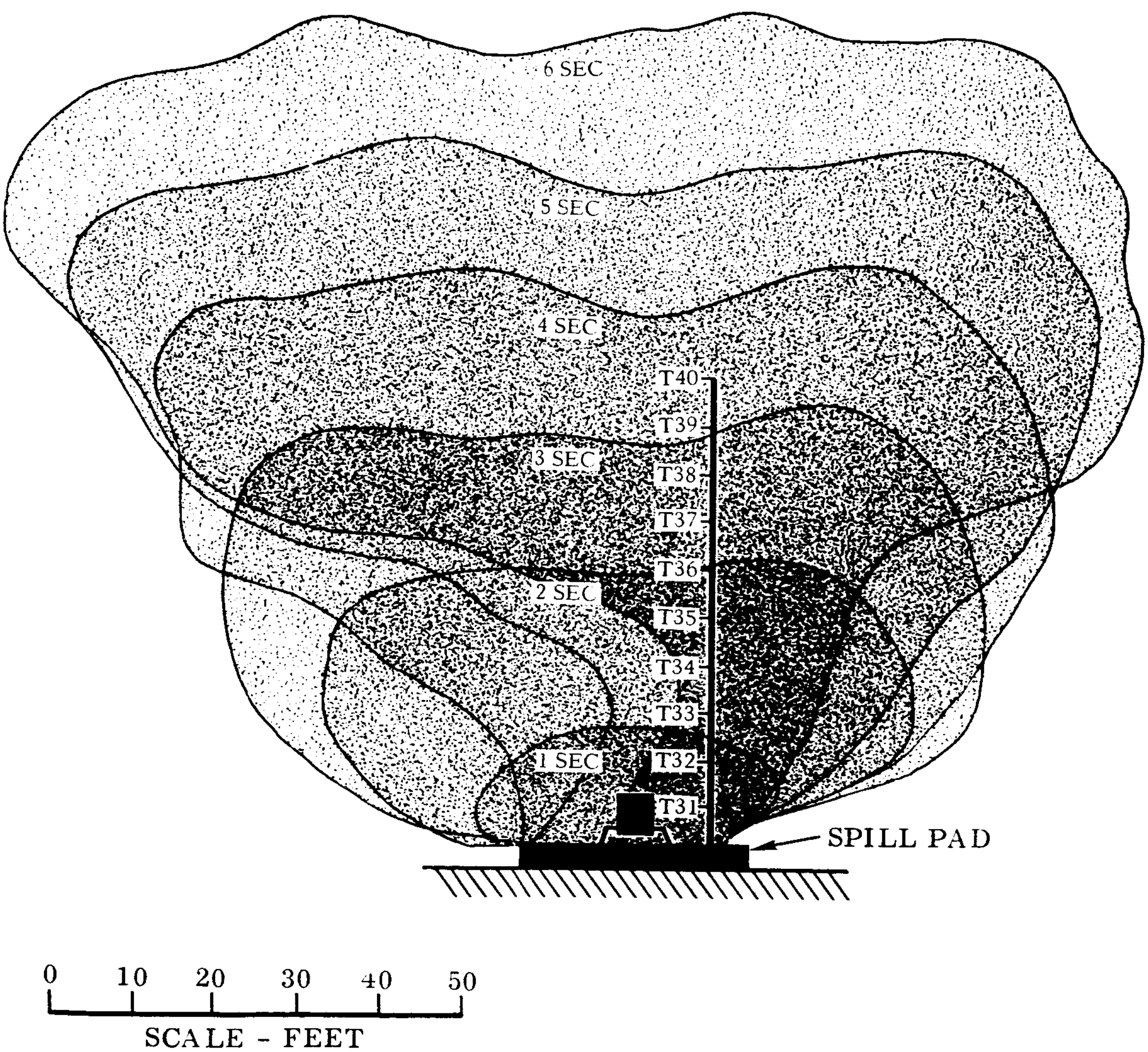


Figure 5-59. Scale Drawing of Test No. 27 Cloud Development

The lower thermocouples up through T34 (which was 24 ft above the spill pad) reached a peak temperature at approximately 2.5 sec. The thermocouples above T34 (up to T40 at 60-ft elevation) showed a progressively later and a much lower peak, indicating that the fireball had lost most of its temperature differential. Figure 5-60 illustrates the cloud top, midposition, bottom, and volume as determined from the highspeed films.

Although it is not possible to make an accurate accounting of the heat release and losses, it is instructive to calculate heat quantities for a typical test. In test 27, 110 lb of charcoal was consumed. Assuming an idealized reaction in which the charcoal is oxidized by the LF_2 and O_2 to form CO_2 and CF_4, approximately 17,000 Btu would be released per lb of charcoal consumed. This would give a total heat release of 1,870,000 Btu. There would be approximately 2150 lb of oxidizer remaining in excess of that required in the assumed reaction. This would absorb approximately 200,000 Btu if completely vaporized, leaving a cloud of cold oxidizer gas to mix with the hot gases. If complete mixing is assumed, approximately 210,000 Btu is required to raise this mass of gas to ambient temperature. Thus, the total heat absorbed would be 410,000 Btu -- considerably less than the minimum calculated heat release.

From Figure 5-59 it appears that by five and a half seconds after initiation, combustion was complete and the cloud had separated from the spill pad. At that time the estimated cloud volume, as shown in Figure 5-60, is 480,000 ft^3. From the cloud buoyancy calculations presented in Figure 33 of Part 2, the average cloud temperature at this point would appear to be about 25°F above ambient. This represents an additional sensible heat of approximately 200,000 Btu. Thus, 610,000 Btu of the 1,870,000 difference is represented by the radiation losses.

Large radiation losses would be expected due to the high initial gas temperatures. Thus, the calculated heat balance appears reasonable and tends to substantiate the maximum assumed value of heat release from the combustion of the fluorine and charcoal. However, since all these processes occurred simultaneously, it is difficult to obtain an accurate picture from the limited instrumentation available. The calculations serve only to give a qualitative accounting of the energy release during the reaction.

Although high percentages of the oxidizer may have been consumed in some of the runs as indicated in Table 5-5, the combustion efficiency was rather poor due to the difficulty of providing sufficient charcoal surface area for the reaction. This indicates that the use of

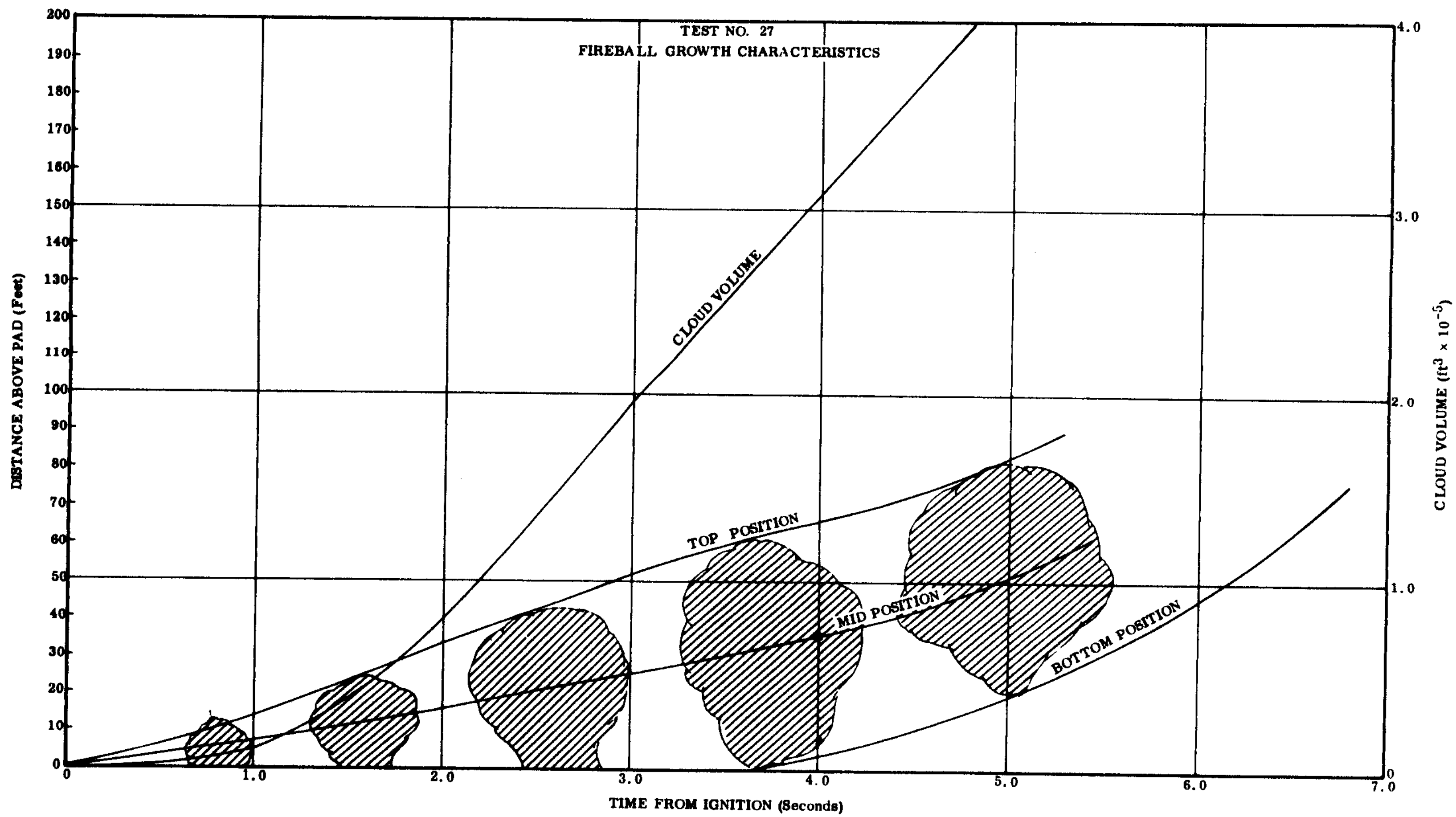


Figure 5-60. Test No. 27 Fireball Characteristics

charcoal as a decontamination means -- i.e., converting liquid F_2 from a line leak or tank rupture to inert CF_4 -- requires a much more effective means of deploying the charcoal to ensure that adequate charcoal surface is available to react all of the liquid F_2. A simple, open charcoal-covered surface as used in these tests is inadequate for efficient decontamination purposes.

c. Correlation with Theory

The experimental cloud data from the scale tests were correlated with a mathematical model. A method of determining the penetration of a given inversion by a cloud of known buoyancy or energy is presented in Part 2. This method was applied to the cloud data from a 91,000-lb LH_2/LO_2 Saturn S-IV test conducted at Edwards Rocket Base. It was shown that a full-scale hot source, such as the Saturn S-IV, would break through a major portion of the temperature inversion conditions encountered at the Sycamore Test Site.

d. Fluorine and Hydrogen Fluoride Concentrations

The data for the downwind measurements of fluorine and hydrogen fluoride for the hot spills is presented in Figures 5-65 through 5-84. Abbreviations used in these illustrations are explained in Table 5-6. The total dosage and peak concentrations are tabulated for each station used for each test. The corresponding station location is shown on a map of the test area and the mean wind velocity and direction at the spill site is indicated. A projection of the cloud size and path is shown on a near field section of the map for correlation with the fluorine and hydrogen fluoride measurements. The centerline of the plume as determined by FP measurements is also shown for comparison. Generally, good agreement is apparent between cloud track, FP track, and dosages.

E. Hydrolysis of Fluorine to Hydrogen Fluoride

The hydrolysis rate of gaseous F_2 to HF by reaction with atmospheric water vapor was determined. The allowable concentration and dosage of HF are 10 times those of F_2. Therefore, formation of HF in large quantities from a release of F_2 has the same effect as increasing the available exclusion distance by $\sqrt{10}$ for that portion of F_2 converted to HF.

Instrumentation was deployed for each F_2 release to obtain F_2 and HF concentrations simultaneously at the same point. This data revealed the rate and quantity of conversion since HF was released at the source point only for the two tests in which RP-1 was the fuel. The ratio of observed HF to F_2 dose is plotted against time and distance in Figures 5-85 and 5-86. (The data used for these illustrations was extracted from Figures 5-65 through 5-84.) HF data beyond 500 ft was not used in support of the hydrolysis analysis because the values of the dosages measured were below the sensitivity of the HF instruments and were not considered reliable although the data falls within the same range out to the limit of observation (10 minutes or approximately 10,000 ft depending upon wind velocity). It appears from the data that a volume conversion of at least 4 to 1 (4 ft^3 HF from 5 ft^3 F_2) in 1 minute or approximately 500 ft will occur. Other work (Reference 6) suggests that the rate of conversion is much lower at lower concentrations. This may be verified by fluorine observations at a distance of 7500 ft in the range of a fraction of 1 ppm-min which would not be likely if the original high conversion rate had persisted.

That water is present in the atmosphere for fluorine reaction is apparent by calculation of the cloud volume. For example, on the driest day of the test period, the absolute humidity was 20 grains of moisture per pound of dry air. The volume of the test cloud was $27 \times 10^6 ft^3$ after 14 seconds. This cloud contained 5000 lb of H_2O, or approximately five times the quantity required to react with the 1000 lb of F_2 in the cloud. In 2 minutes the volume increased by a factor of 10, further increasing the available water.

Table 5-6. Abbreviations Used in F_2 and HF Dose Plots (Figures 5-61 through 5-84)

CP: Peak concentration in parts per million by volume

R-1 through R-4: Convair Chemical Fluorine and Fluoride Dosimeter, Serial numbers FLOX 00509-1 through FLOX 00509-4

K-1 through K-6: Convair Electrochemical Fluorine Indicator-Recorder, Serial numbers FLOX 00510-1 through FLOX 00510-6

T-1 through T-3: TRACERLAB Fluorine Indicator-Recorder, Model KR-85, Serial numbers KR-85-1 through KR-85-3

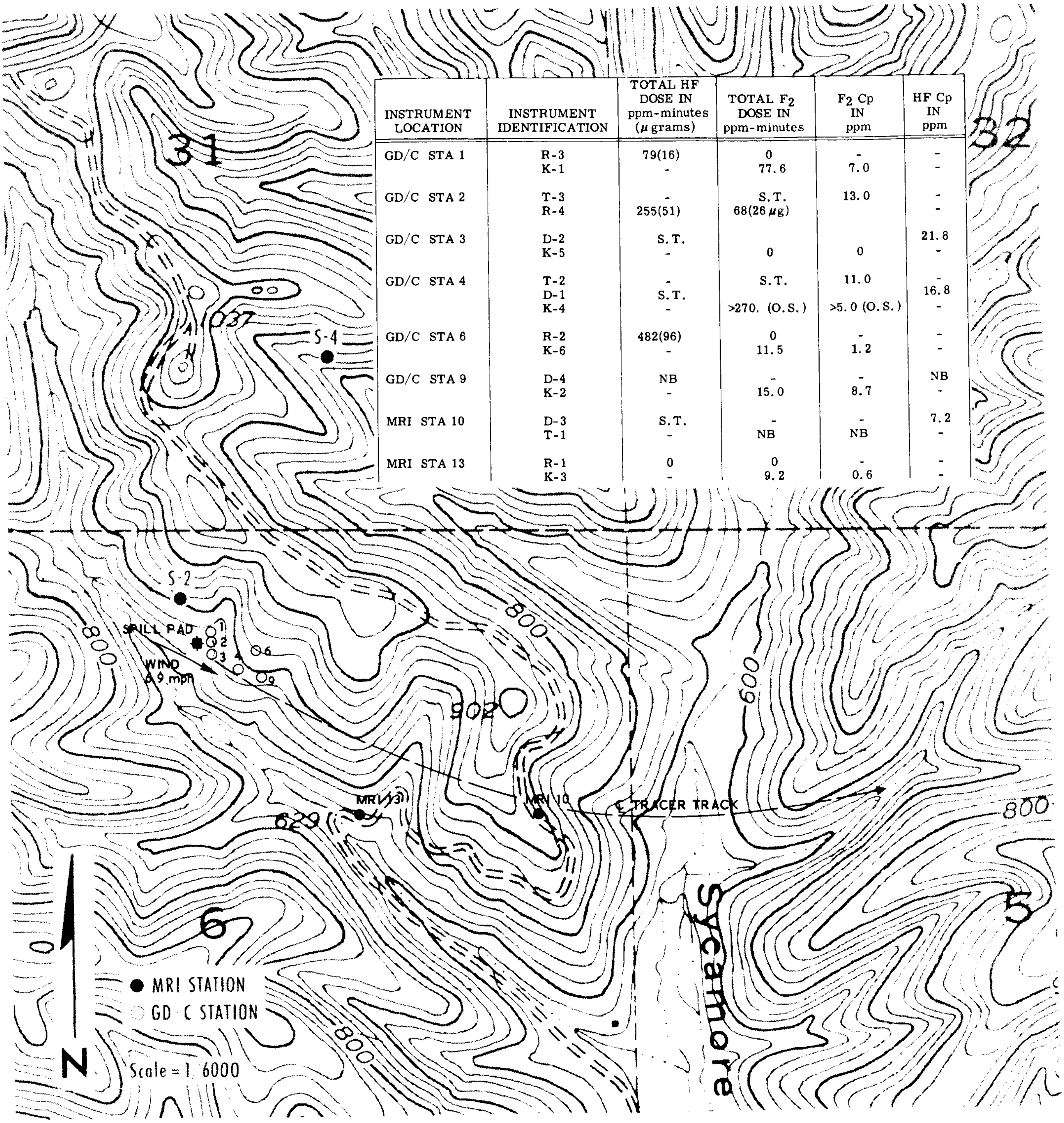
D-1 through D-4: DAVIS HF Indicator-Recorder, Serial numbers D-159 through D-162

S T: Recorder was running too slow to measure time

O S: Recorder off scale

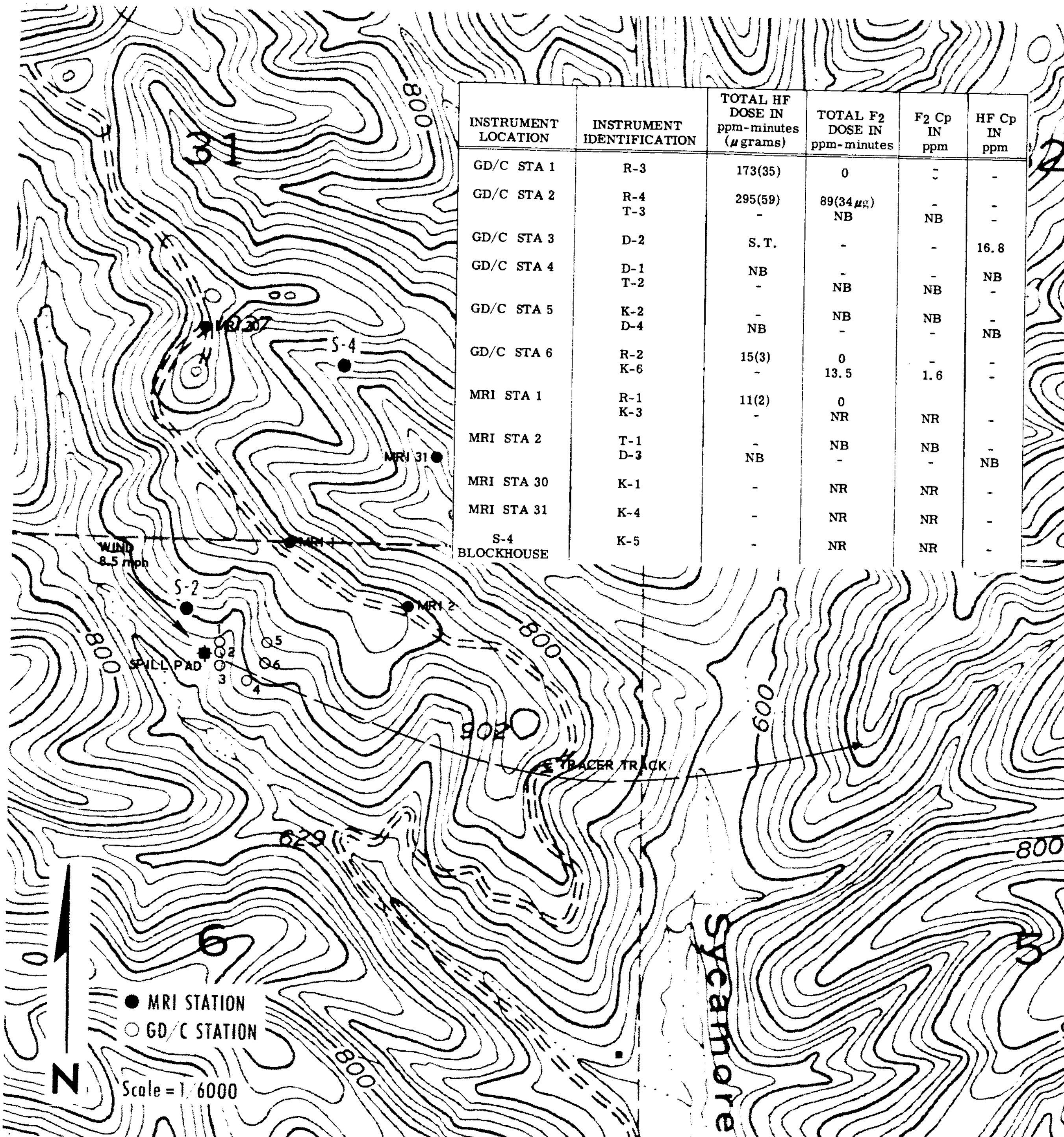
NB: Recorder battery failed and no data was obtained

NR: Invalid data from recorder malfunction such as zero drift



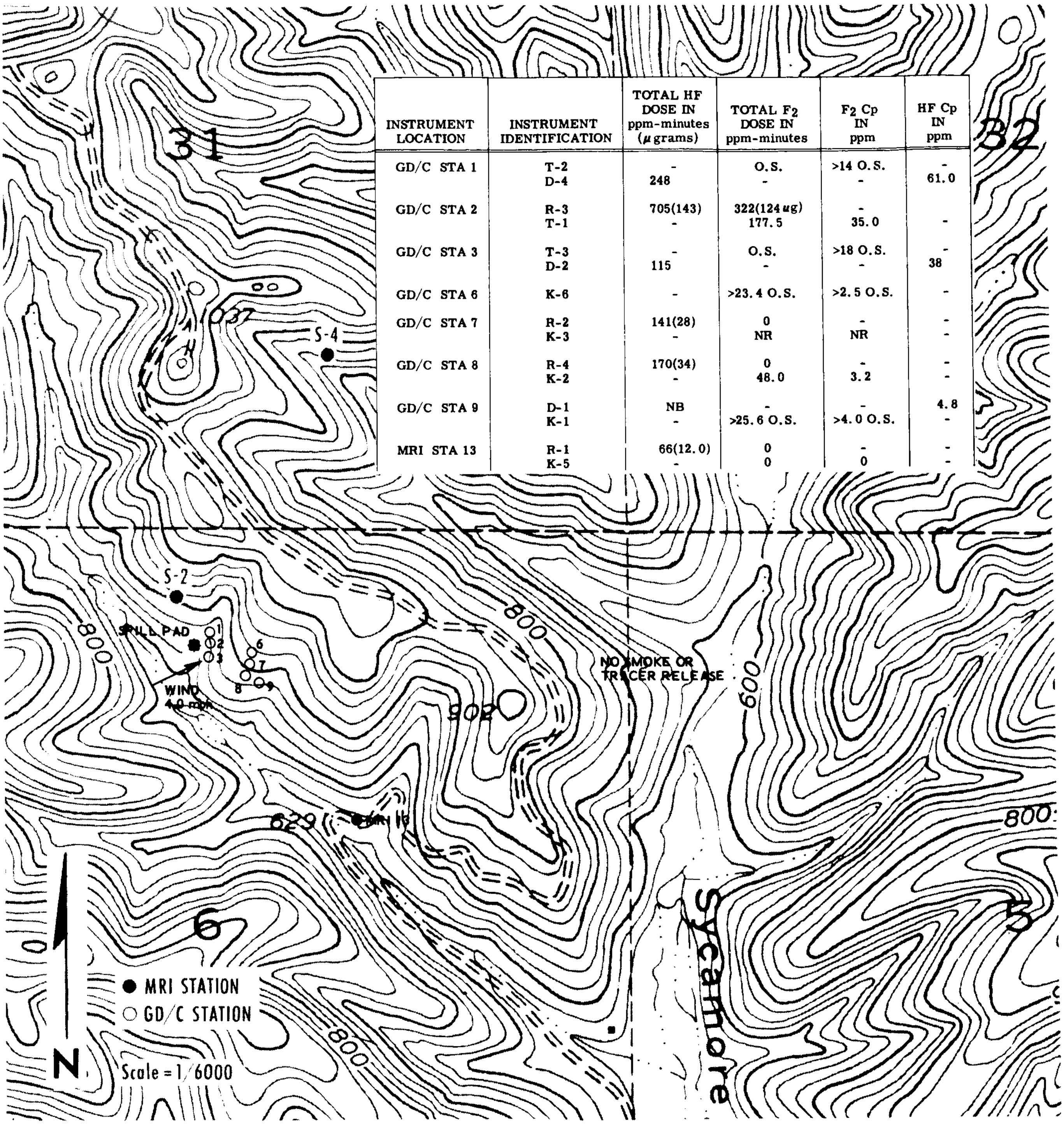
INSTRUMENT LOCATION	INSTRUMENT IDENTIFICATION	TOTAL HF DOSE IN ppm-minutes (μ grams)	TOTAL F_2 DOSE IN ppm-minutes	F_2 Cp IN ppm	HF Cp IN ppm
GD/C STA 1	R-3	79(16)	0	-	-
	K-1	-	77.6	7.0	-
GD/C STA 2	T-3	-	S.T.	13.0	-
	R-4	255(51)	68(26 μg)		-
GD/C STA 3	D-2	S.T.			21.8
	K-5	-	0	0	-
GD/C STA 4	T-2	-	S.T.	11.0	-
	D-1	S.T.			16.8
	K-4	-	>270. (O.S.)	>5.0 (O.S.)	-
GD/C STA 6	R-2	482(96)	0	-	-
	K-6	-	11.5	1.2	-
GD/C STA 9	D-4	NB	-	-	NB
	K-2	-	15.0	8.7	-
MRI STA 10	D-3	S.T.	-	-	7.2
	T-1	-	NB	NB	-
MRI STA 13	R-1	0	0	-	-
	K-3	-	9.2	0.6	-

Figure 5-61. Test No. 13 Near Field F_2 and HF Concentration Data and Plume Trajectory



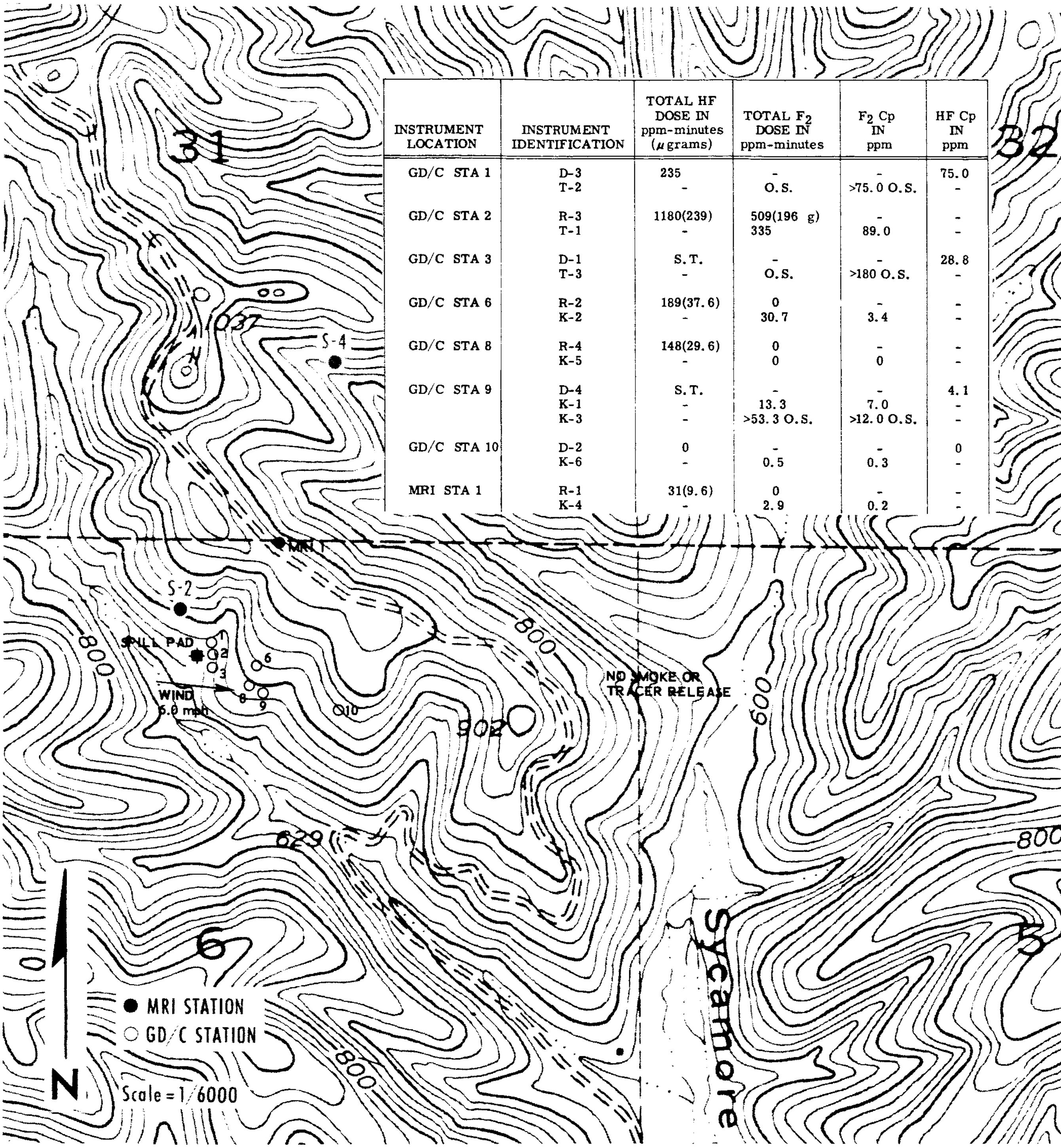
INSTRUMENT LOCATION	INSTRUMENT IDENTIFICATION	TOTAL HF DOSE IN ppm-minutes (μ grams)	TOTAL F_2 DOSE IN ppm-minutes	F_2 Cp IN ppm	HF Cp IN ppm
GD/C STA 1	R-3	173(35)	0	-	-
GD/C STA 2	R-4 T-3	295(59) -	89(34μg) NB	- NB	- -
GD/C STA 3	D-2	S.T.	-	-	16.8
GD/C STA 4	D-1 T-2	NB -	- NB	- NB	NB -
GD/C STA 5	K-2 D-4	- NB	NB -	NB -	- NB
GD/C STA 6	R-2 K-6	15(3) -	0 13.5	- 1.6	- -
MRI STA 1	R-1 K-3	11(2) -	0 NR	NR	-
MRI STA 2	T-1 D-3	- NB	NB -	NB -	- NB
MRI STA 30	K-1	-	NR	NR	-
MRI STA 31	K-4	-	NR	NR	-
S-4 BLOCKHOUSE	K-5	-	NR	NR	-

Figure 5-62. Test No. 14 Near Field F_2 and HF Concentration Data and Plume Trajectory



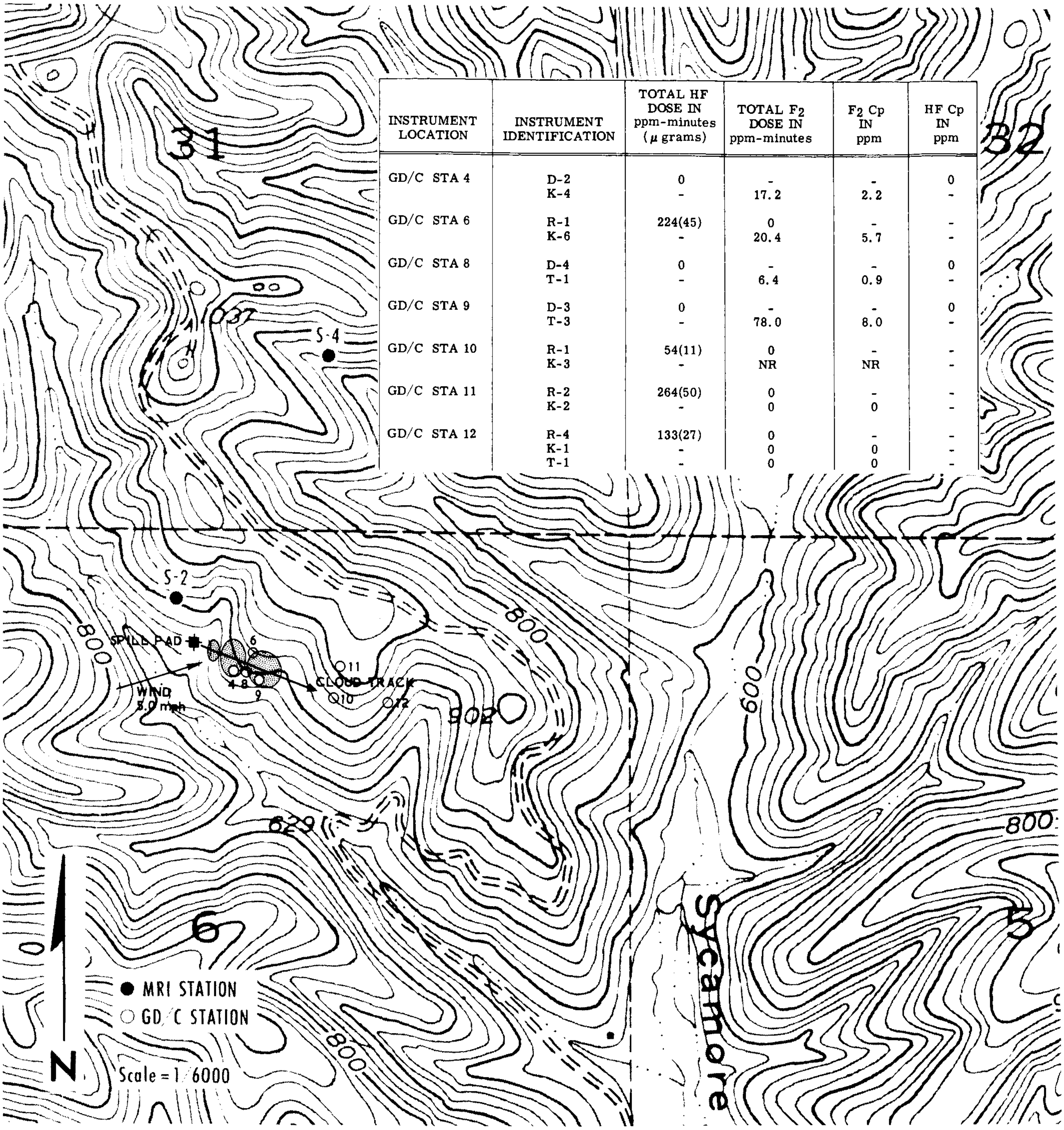
INSTRUMENT LOCATION	INSTRUMENT IDENTIFICATION	TOTAL HF DOSE IN ppm-minutes (μgrams)	TOTAL F_2 DOSE IN ppm-minutes	F_2 Cp IN ppm	HF Cp IN ppm
GD/C STA 1	T-2 D-4	- 248	O.S. -	>14 O.S. -	- 61.0
GD/C STA 2	R-3 T-1	705(143) -	322(124 μg) 177.5	- 35.0	-
GD/C STA 3	T-3 D-2	- 115	O.S. -	>18 O.S. -	- 38
GD/C STA 6	K-6	-	>23.4 O.S.	>2.5 O.S.	-
GD/C STA 7	R-2 K-3	141(28) -	0 NR	- NR	- -
GD/C STA 8	R-4 K-2	170(34) -	0 48.0	- 3.2	- -
GD/C STA 9	D-1 K-1	NB -	- >25.6 O.S.	- >4.0 O.S.	4.8 -
MRI STA 13	R-1 K-5	66(12.0) -	0 0	- 0	- -

Figure 5-63. Test No. 16 Near Field F_2 and HF Concentration Data



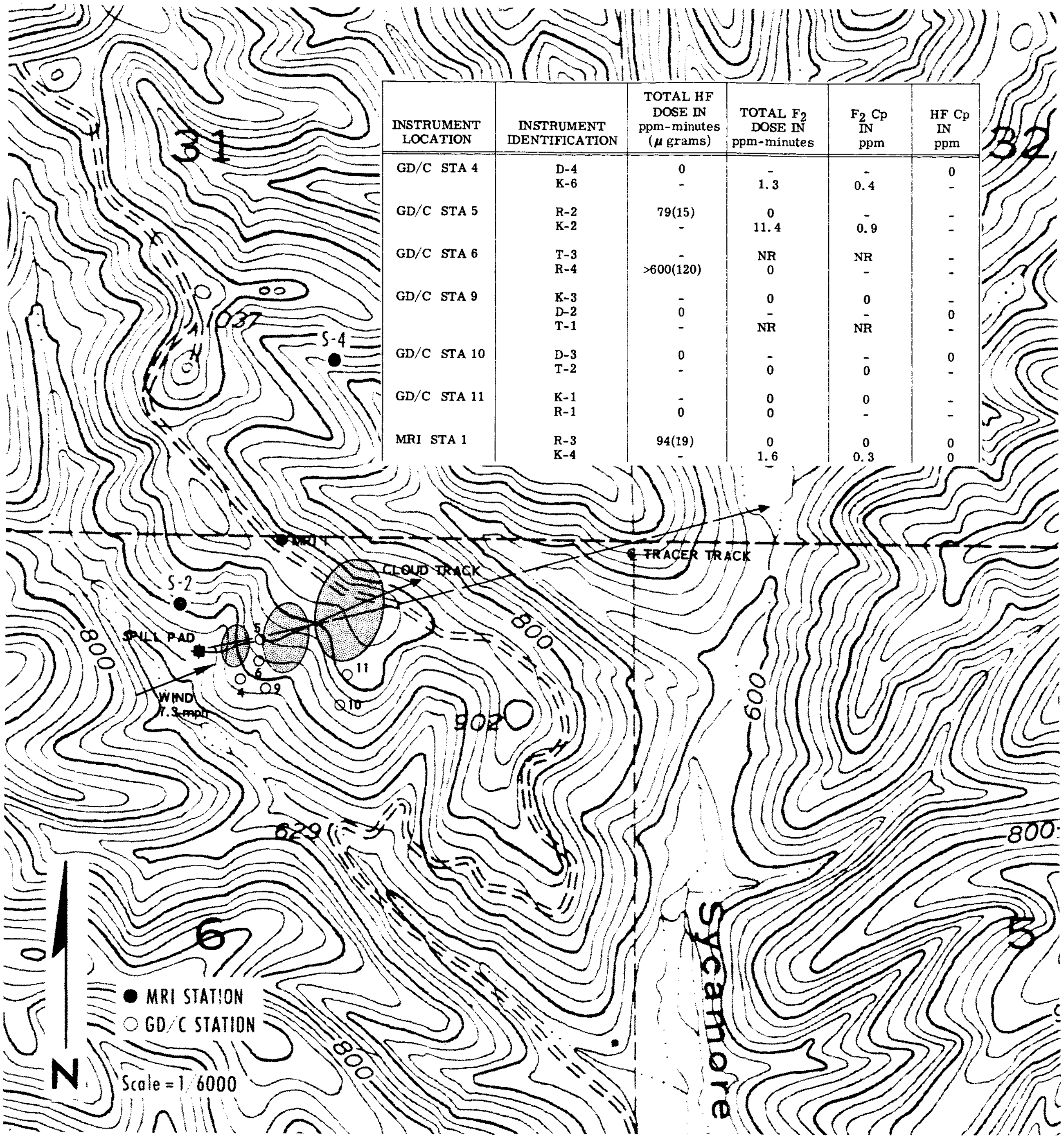
INSTRUMENT LOCATION	INSTRUMENT IDENTIFICATION	TOTAL HF DOSE IN ppm-minutes (μgrams)	TOTAL F_2 DOSE IN ppm-minutes	F_2 Cp IN ppm	HF Cp IN ppm
GD/C STA 1	D-3	235	-	-	75.0
	T-2	-	O.S.	>75.0 O.S.	-
GD/C STA 2	R-3	1180(239)	509(196 g)	-	-
	T-1	-	335	89.0	-
GD/C STA 3	D-1	S.T.	-	-	28.8
	T-3	-	O.S.	>180 O.S.	-
GD/C STA 6	R-2	189(37.6)	0	-	-
	K-2	-	30.7	3.4	-
GD/C STA 8	R-4	148(29.6)	0	-	-
	K-5	-	0	0	-
GD/C STA 9	D-4	S.T.	-	-	4.1
	K-1	-	13.3	7.0	-
	K-3	-	>53.3 O.S.	>12.0 O.S.	-
GD/C STA 10	D-2	0	-	-	0
	K-6	-	0.5	0.3	-
MRI STA 1	R-1	31(9.6)	0	-	-
	K-4	-	2.9	0.2	-

Figure 5-64. Test No. 17 Near Field F_2 and HF Concentration Data



INSTRUMENT LOCATION	INSTRUMENT IDENTIFICATION	TOTAL HF DOSE IN ppm-minutes (μ grams)	TOTAL F_2 DOSE IN ppm-minutes	F_2 Cp IN ppm	HF Cp IN ppm
GD/C STA 4	D-2	0	-	-	0
	K-4	-	17.2	2.2	-
GD/C STA 6	R-1	224(45)	0	-	-
	K-6	-	20.4	5.7	-
GD/C STA 8	D-4	0	-	-	0
	T-1	-	6.4	0.9	-
GD/C STA 9	D-3	0	-	-	0
	T-3	-	78.0	8.0	-
GD/C STA 10	R-1	54(11)	0	-	-
	K-3	-	NR	NR	-
GD/C STA 11	R-2	264(50)	0	-	-
	K-2	-	0	0	-
GD/C STA 12	R-4	133(27)	0	-	-
	K-1	-	0	0	-
	T-1	-	0	0	-

Figure 5-65. Test No. 18 Near Field F_2 and HF Concentration Data and Plume Trajectory



INSTRUMENT LOCATION	INSTRUMENT IDENTIFICATION	TOTAL HF DOSE IN ppm-minutes (μ grams)	TOTAL F_2 DOSE IN ppm-minutes	F_2 Cp IN ppm	HF Cp IN ppm
GD/C STA 4	D-4	0	-	-	0
	K-6	-	1.3	0.4	-
GD/C STA 5	R-2	79(15)	0	-	-
	K-2	-	11.4	0.9	-
GD/C STA 6	T-3	-	NR	NR	-
	R-4	>600(120)	0	-	-
GD/C STA 9	K-3	-	0	0	-
	D-2	0	-	-	0
	T-1	-	NR	NR	-
GD/C STA 10	D-3	0	-	-	0
	T-2	-	0	0	-
GD/C STA 11	K-1	-	0	0	-
	R-1	0	0	-	-
MRI STA 1	R-3	94(19)	0	0	0
	K-4	-	1.6	0.3	0

Figure 5-66. Test No. 19 Near Field F_2 and HF Concentration Data and Plume Trajectory

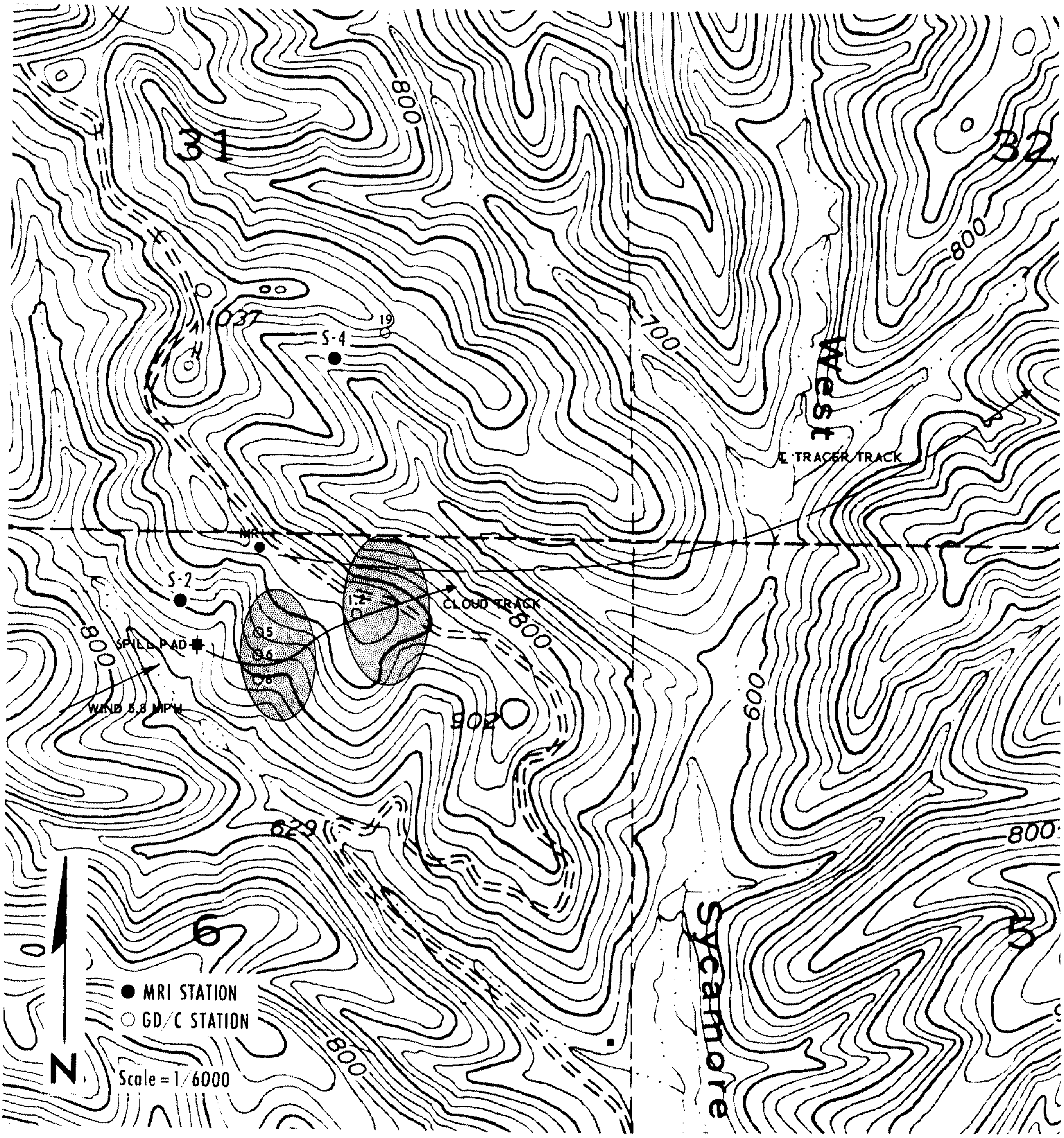
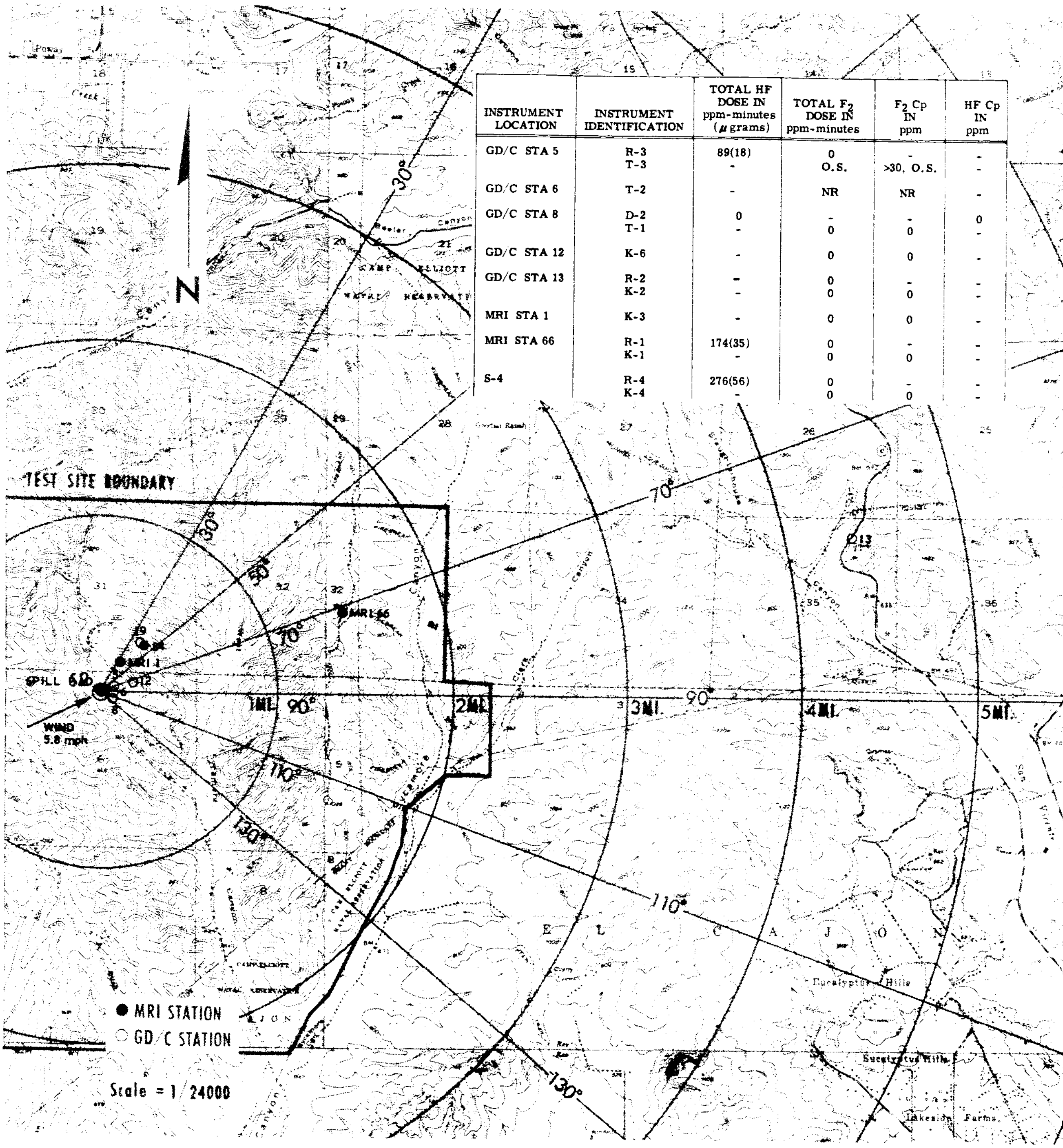


Figure 5-67. Test No. 20 Near Field F_2 and HF Concentration Data and Plume Trajectory



INSTRUMENT LOCATION	INSTRUMENT IDENTIFICATION	TOTAL HF DOSE IN ppm-minutes (μ grams)	TOTAL F_2 DOSE IN ppm-minutes	F_2 Cp IN ppm	HF Cp IN ppm
GD/C STA 5	R-3	89(18)	0	-	-
	T-3	-	O.S.	>30, O.S.	-
GD/C STA 6	T-2	-	NR	NR	-
GD/C STA 8	D-2	0	-	-	0
	T-1	-	0	0	-
GD/C STA 12	K-6	-	0	0	-
GD/C STA 13	R-2	-	0	-	-
	K-2	-	0	0	-
MRI STA 1	K-3	-	0	0	-
MRI STA 66	R-1	174(35)	0	-	-
	K-1	-	0	0	-
S-4	R-4	276(56)	0	-	-
	K-4	-	0	0	-

Figure 5-68. Test No. 20 Far Field F_2 and HF Concentration Data

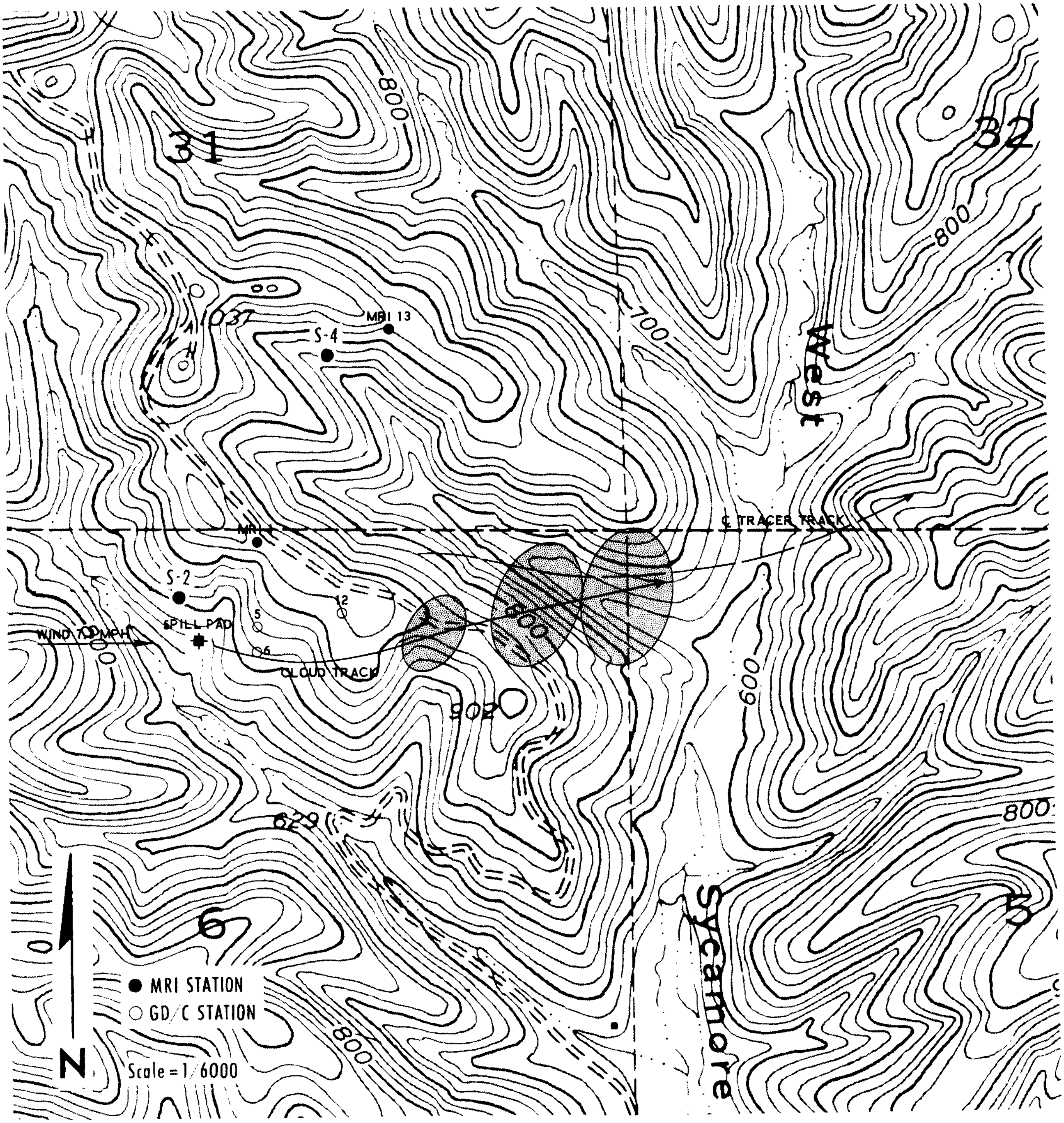
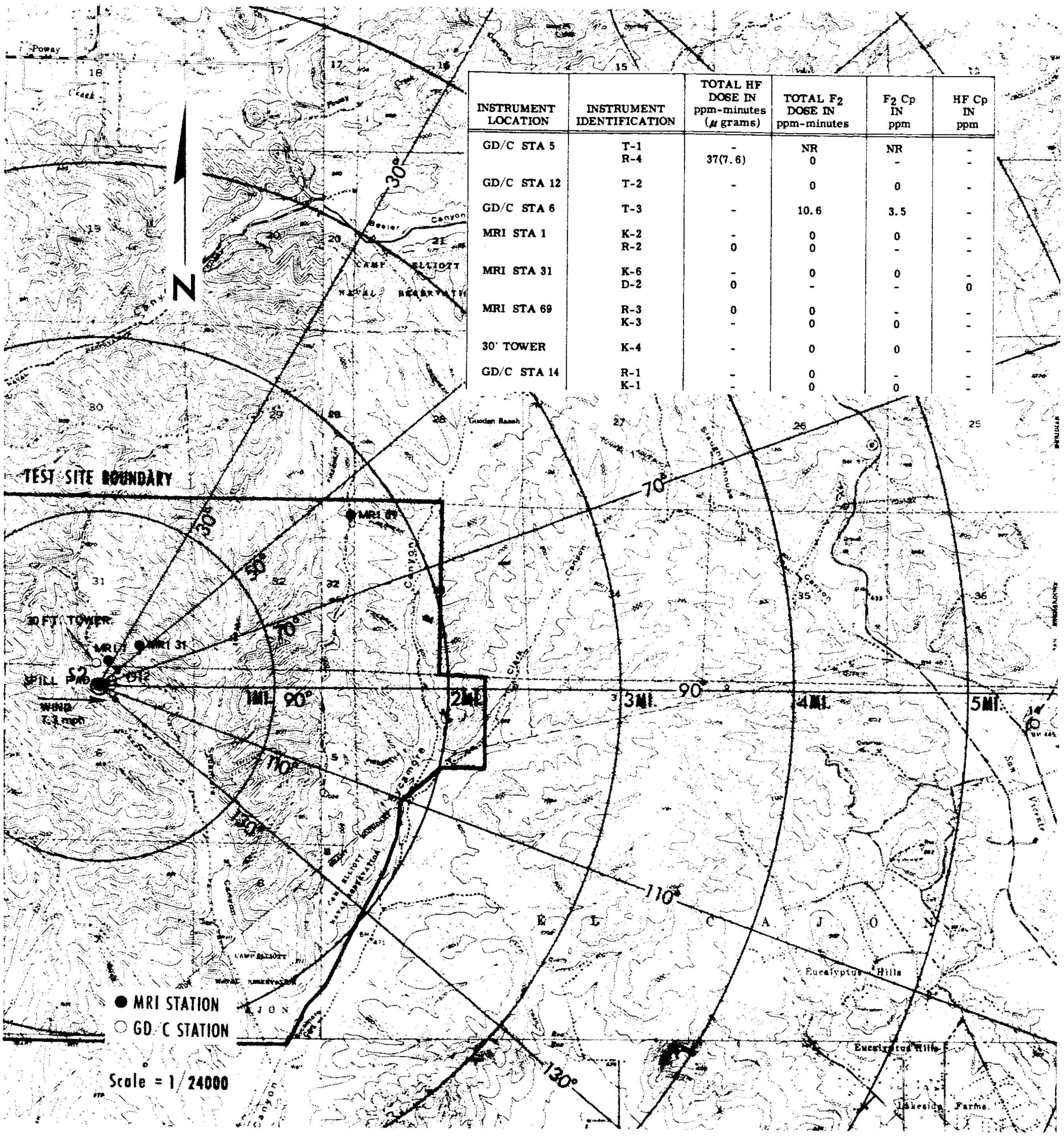


Figure 5-69. Test No. 21 Near Field F_2 and HF Concentration Data and Plume Trajectory



INSTRUMENT LOCATION	INSTRUMENT IDENTIFICATION	TOTAL HF DOSE IN ppm-minutes (μ grams)	TOTAL F_2 DOSE IN ppm-minutes	F_2 Cp IN ppm	HF Cp IN ppm
GD/C STA 5	T-1	-	NR	NR	-
	R-4	37(7.6)	0	-	-
GD/C STA 12	T-2	-	0	0	-
GD/C STA 6	T-3	-	10.6	3.5	-
MRI STA 1	K-2	-	0	0	-
	R-2	0	0	-	-
MRI STA 31	K-6	-	0	0	-
	D-2	0	-	-	0
MRI STA 69	R-3	0	0	-	-
	K-3	-	0	0	-
30' TOWER	K-4	-	0	0	-
GD/C STA 14	R-1	-	0	-	-
	K-1	-	0	0	-

Figure 5-70. Test No. 21 Far Field F_2 and HF Concentration Data

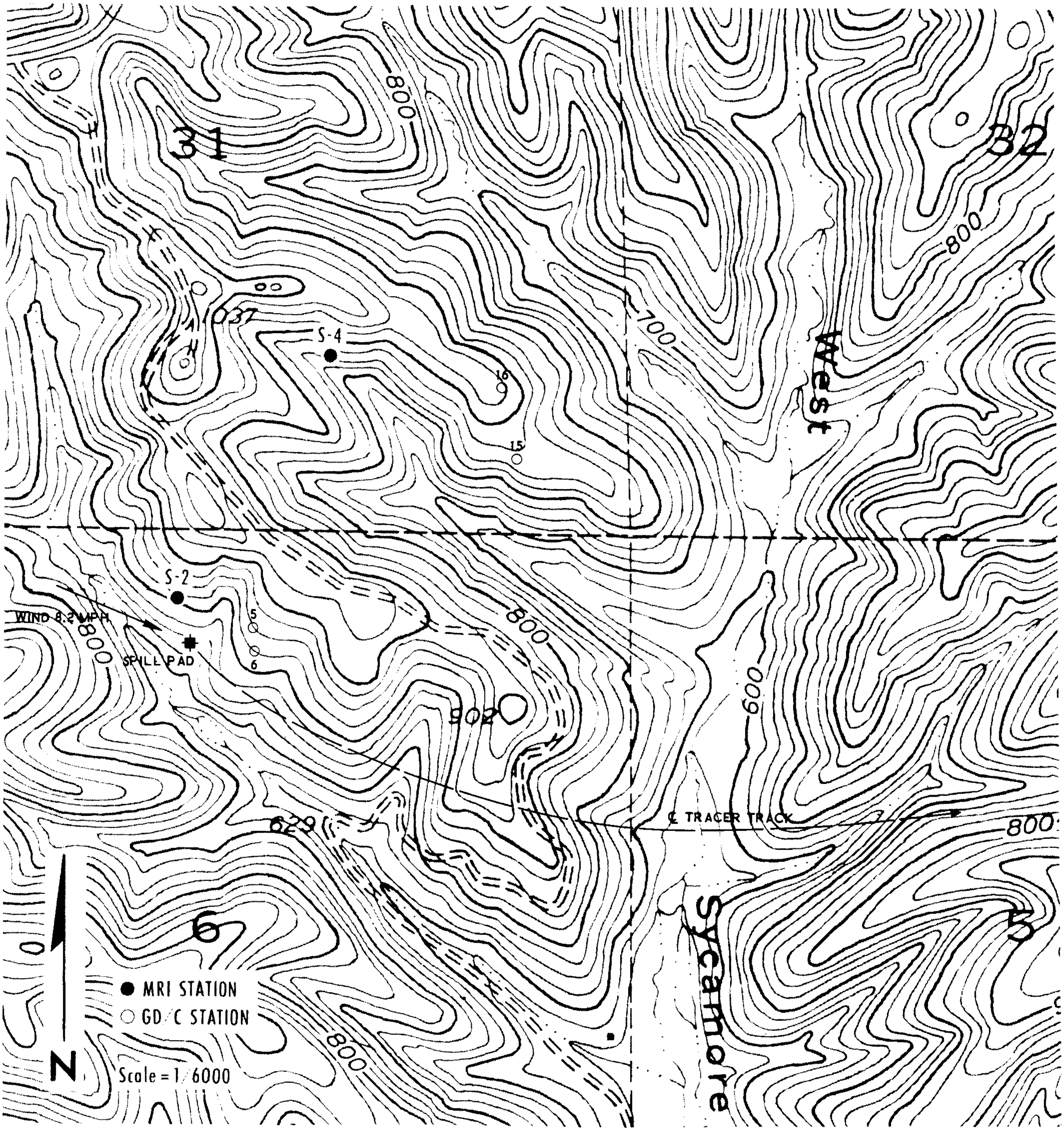


Figure 5-71. Test No. 22 Near Field F_2 and HF Concentration Data and Plume Trajectory

INSTRUMENT LOCATION	INSTRUMENT IDENTIFICATION	TOTAL HF DOSE IN ppm-minutes (μ grams)	TOTAL F_2 DOSE IN ppm-minutes	F_2 Cp IN ppm	HF Cp IN ppm
GD/C STA 5	T-3	-	0	0	-
GD/C STA 6	T-1	-	0	0	-
GD/C STA 14	R-3 K-1	- -	0 0	- 0	- -
GD/C STA 15	T-2	-	0	0	-
GD/C STA 16	K-6 D-2	- 0	0 -	0 -	- 0
MRI STA 62	R-2 K-2	74(15) -	0 0	- 0	- -
MRI STA 63	R-1 K-3	71(14) -	0 0	- 0	- -
MRI STA 64	R-4 K-4	79(16) -	0 0	 0	 -

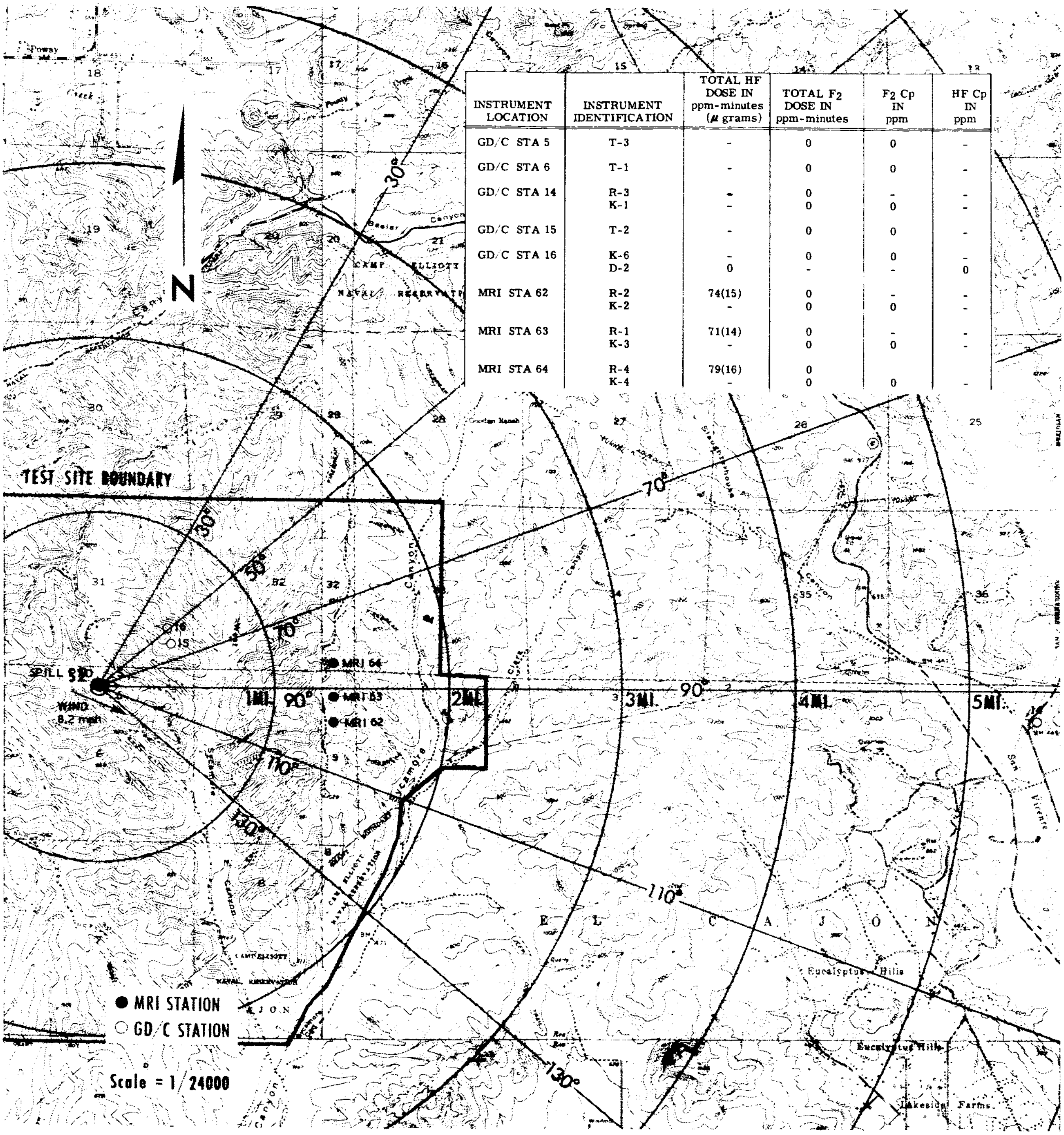


Figure 5-72. Test No. 22 Far Field F_2 and HF Concentration Data

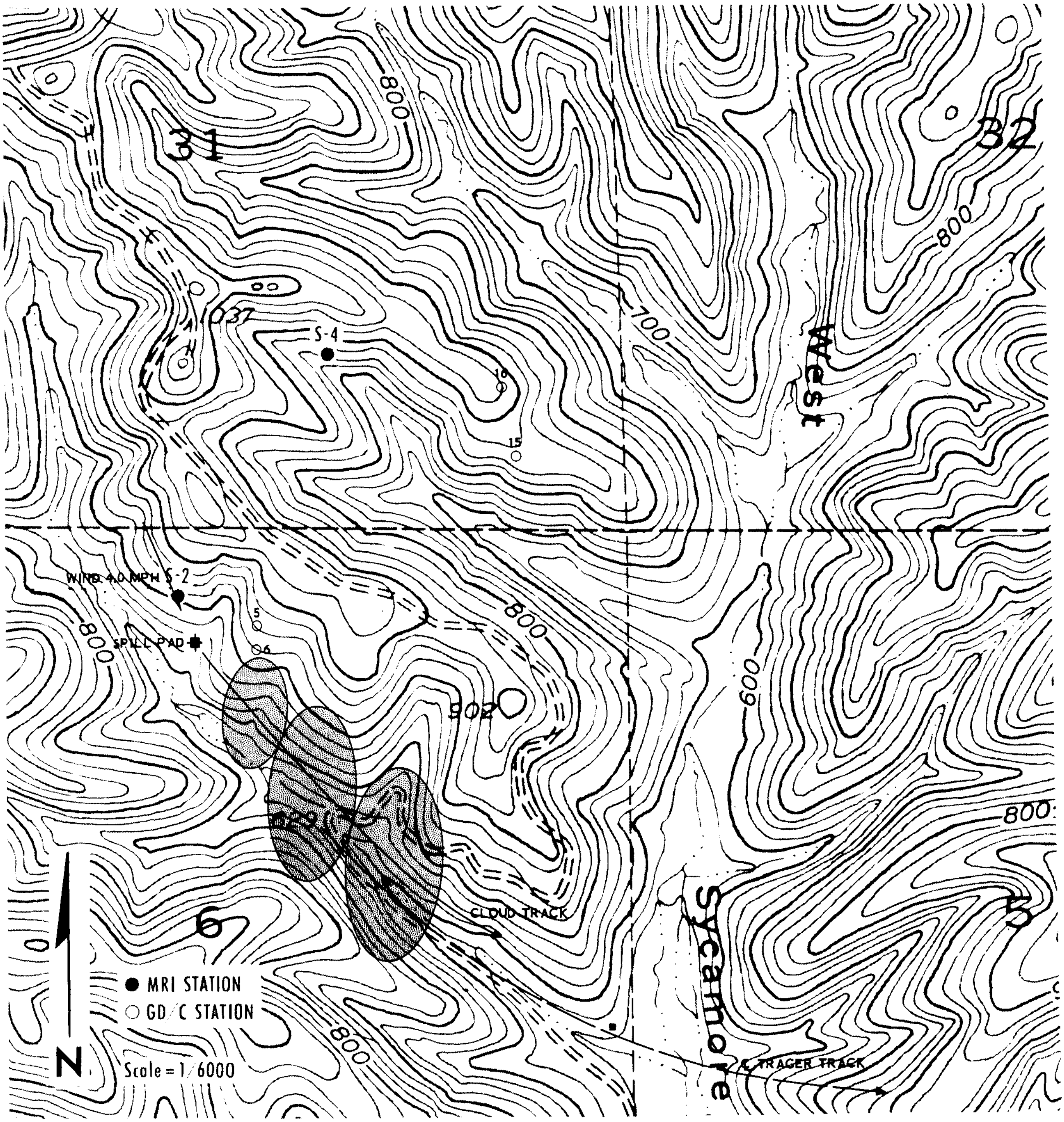
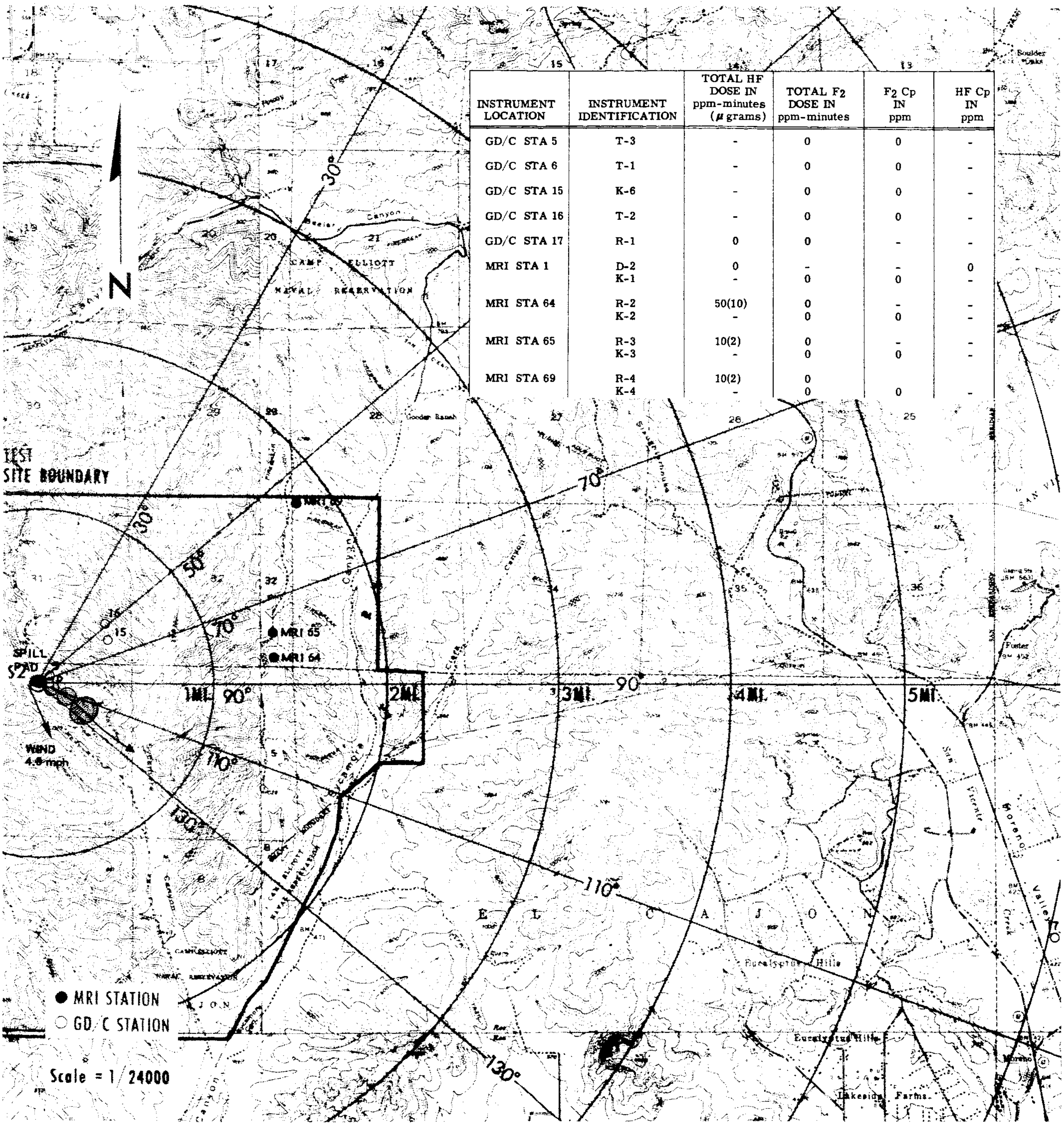


Figure 5-73. Test No. 23 Near Field F_2 and HF Concentration Data and Plume Trajectory



INSTRUMENT LOCATION	INSTRUMENT IDENTIFICATION	TOTAL HF DOSE IN ppm-minutes (μ grams)	TOTAL F_2 DOSE IN ppm-minutes	F_2 Cp IN ppm	HF Cp IN ppm
GD/C STA 5	T-3	-	0	0	-
GD/C STA 6	T-1	-	0	0	-
GD/C STA 15	K-6	-	0	0	-
GD/C STA 16	T-2	-	0	0	-
GD/C STA 17	R-1	0	0	-	-
MRI STA 1	D-2	0	-	-	0
	K-1	-	0	0	-
MRI STA 64	R-2	50(10)	0	-	-
	K-2	-	0	0	-
MRI STA 65	R-3	10(2)	0	-	-
	K-3	-	0	0	-
MRI STA 69	R-4	10(2)	0		
	K-4	-	0	0	-

Figure 5-74. Test No. 23 Far Field F_2 and HF Concentration Data and Plume Trajectory

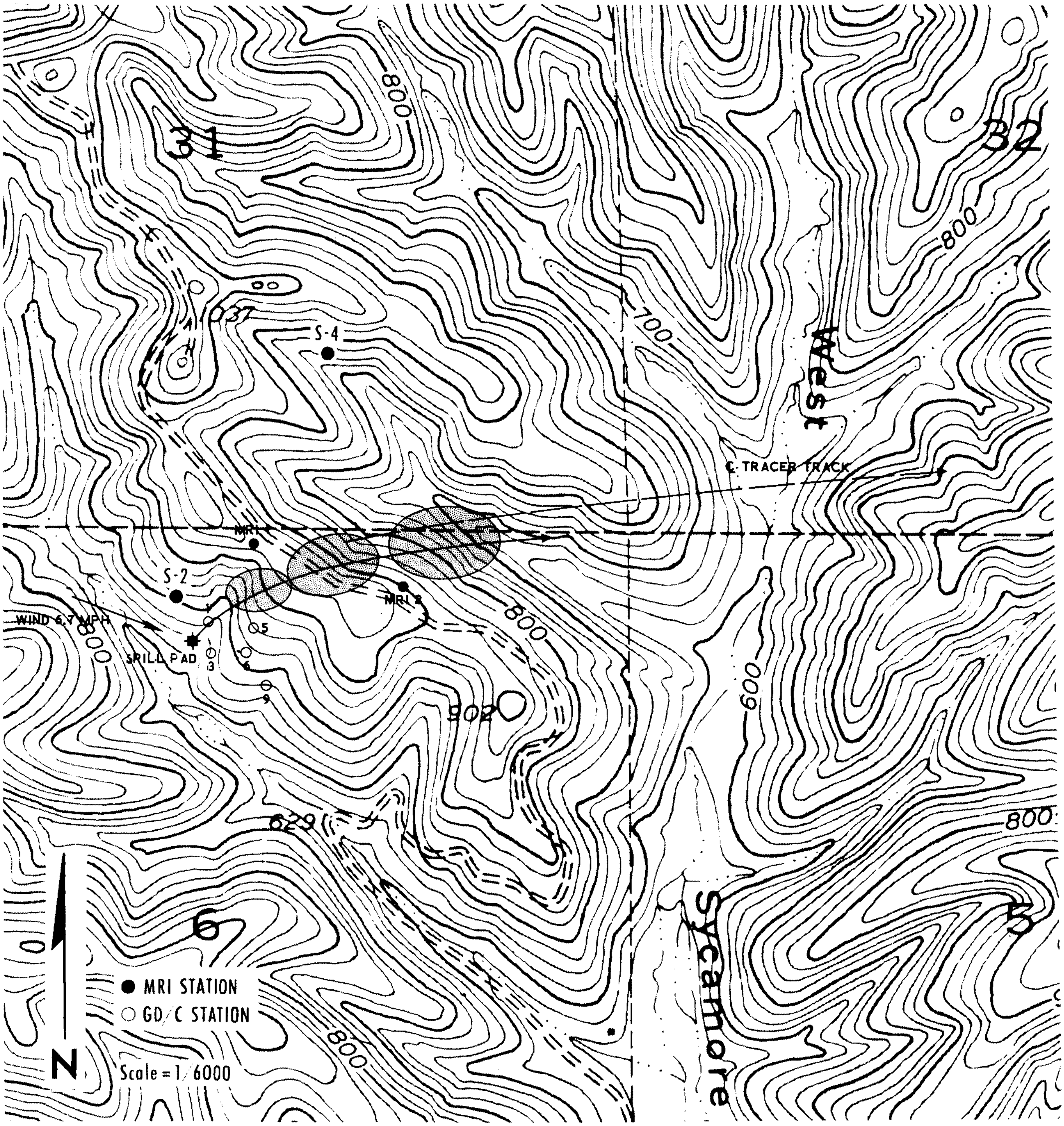
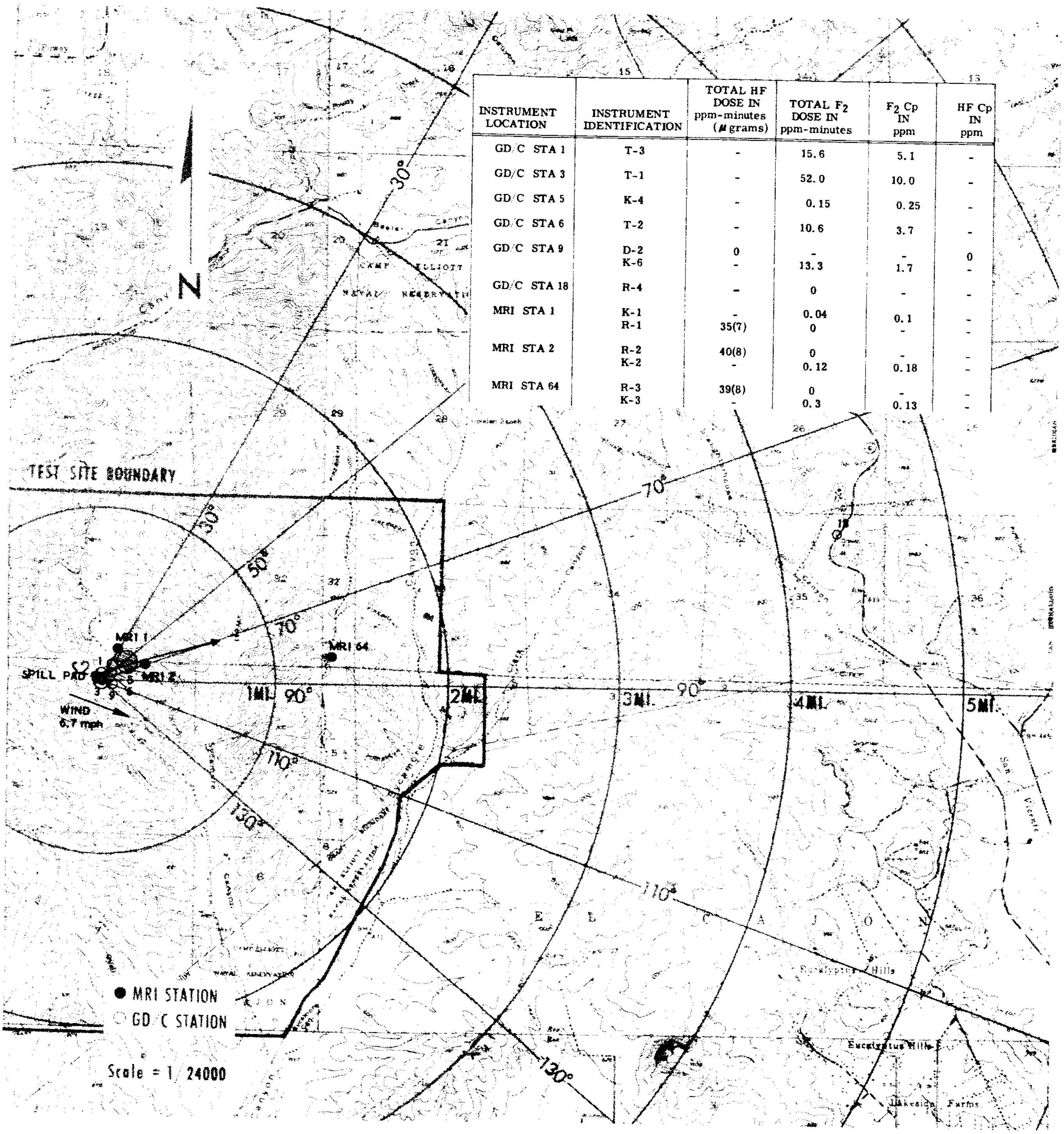


Figure 5-75. Test No. 24 Near Field F_2 and HF Concentration Data and Plume Trajectory



INSTRUMENT LOCATION	INSTRUMENT IDENTIFICATION	TOTAL HF DOSE IN ppm-minutes (μ grams)	TOTAL F_2 DOSE IN ppm-minutes	F_2 Cp IN ppm	HF Cp IN ppm
GD/C STA 1	T-3	-	15.6	5.1	-
GD/C STA 3	T-1	-	52.0	10.0	-
GD/C STA 5	K-4	-	0.15	0.25	-
GD/C STA 6	T-2	-	10.6	3.7	-
GD/C STA 9	D-2	0	-	-	0
	K-6	-	13.3	1.7	-
GD/C STA 18	R-4	-	0	-	-
MRI STA 1	K-1	-	0.04	0.1	-
	R-1	35(7)	0	-	-
MRI STA 2	R-2	40(8)	0	-	-
	K-2	-	0.12	0.18	-
MRI STA 64	R-3	39(8)	0	-	-
	K-3	-	0.3	0.13	-

Figure 5-76. Test No. 24 Far Field F_2 and HF Concentration Data and Plume Trajectory

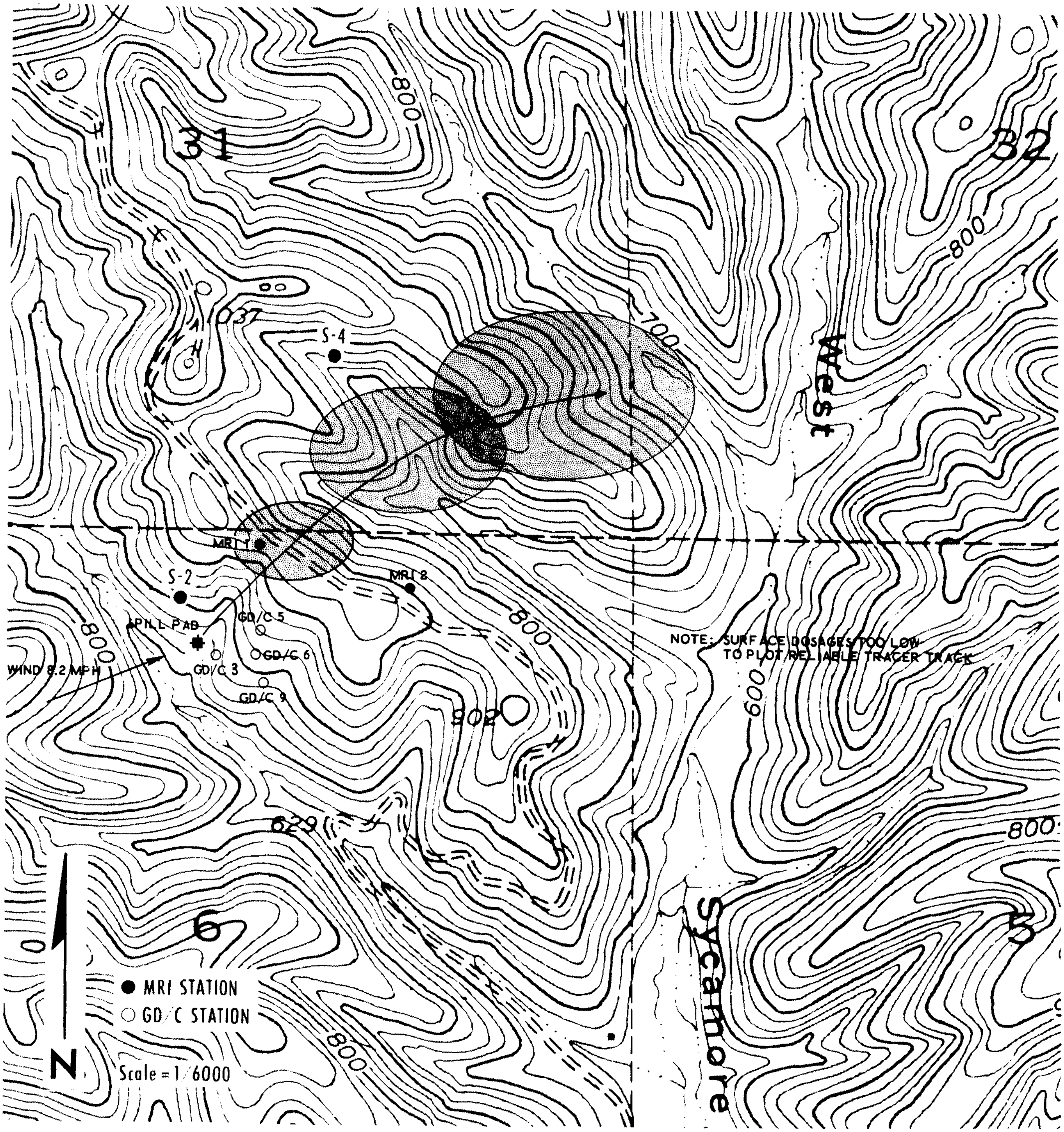
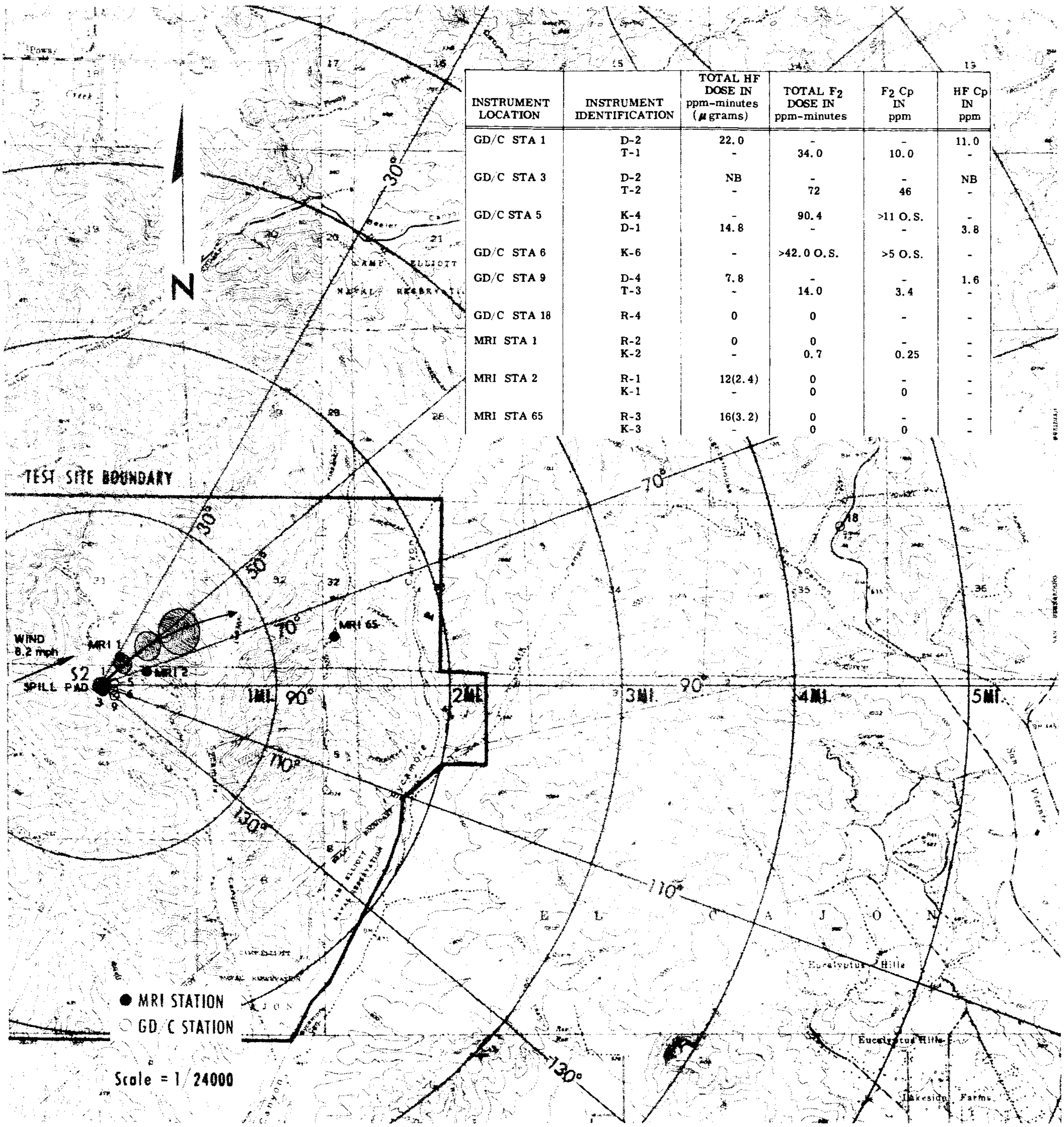


Figure 5-77. Test No. 25 Near Field F_2 and HF Concentration Data and Plume Trajectory



INSTRUMENT LOCATION	INSTRUMENT IDENTIFICATION	TOTAL HF DOSE IN ppm-minutes (µ grams)	TOTAL F_2 DOSE IN ppm-minutes	F_2 Cp IN ppm	HF Cp IN ppm
GD/C STA 1	D-2	22.0	-	-	11.0
	T-1	-	34.0	10.0	-
GD/C STA 3	D-2	NB	-	-	NB
	T-2	-	72	46	-
GD/C STA 5	K-4	-	90.4	>11 O.S.	-
	D-1	14.8	-	-	3.8
GD/C STA 6	K-6	-	>42.0 O.S.	>5 O.S.	-
GD/C STA 9	D-4	7.8	-	-	1.6
	T-3	-	14.0	3.4	-
GD/C STA 18	R-4	0	0	-	-
MRI STA 1	R-2	0	0	-	-
	K-2	-	0.7	0.25	-
MRI STA 2	R-1	12(2.4)	0	-	-
	K-1	-	0	0	-
MRI STA 65	R-3	16(3.2)	0	-	-
	K-3	-	0	0	-

Figure 5-78. Test No. 25 Far Field F_2 and HF Concentration Data and Plume Trajectory

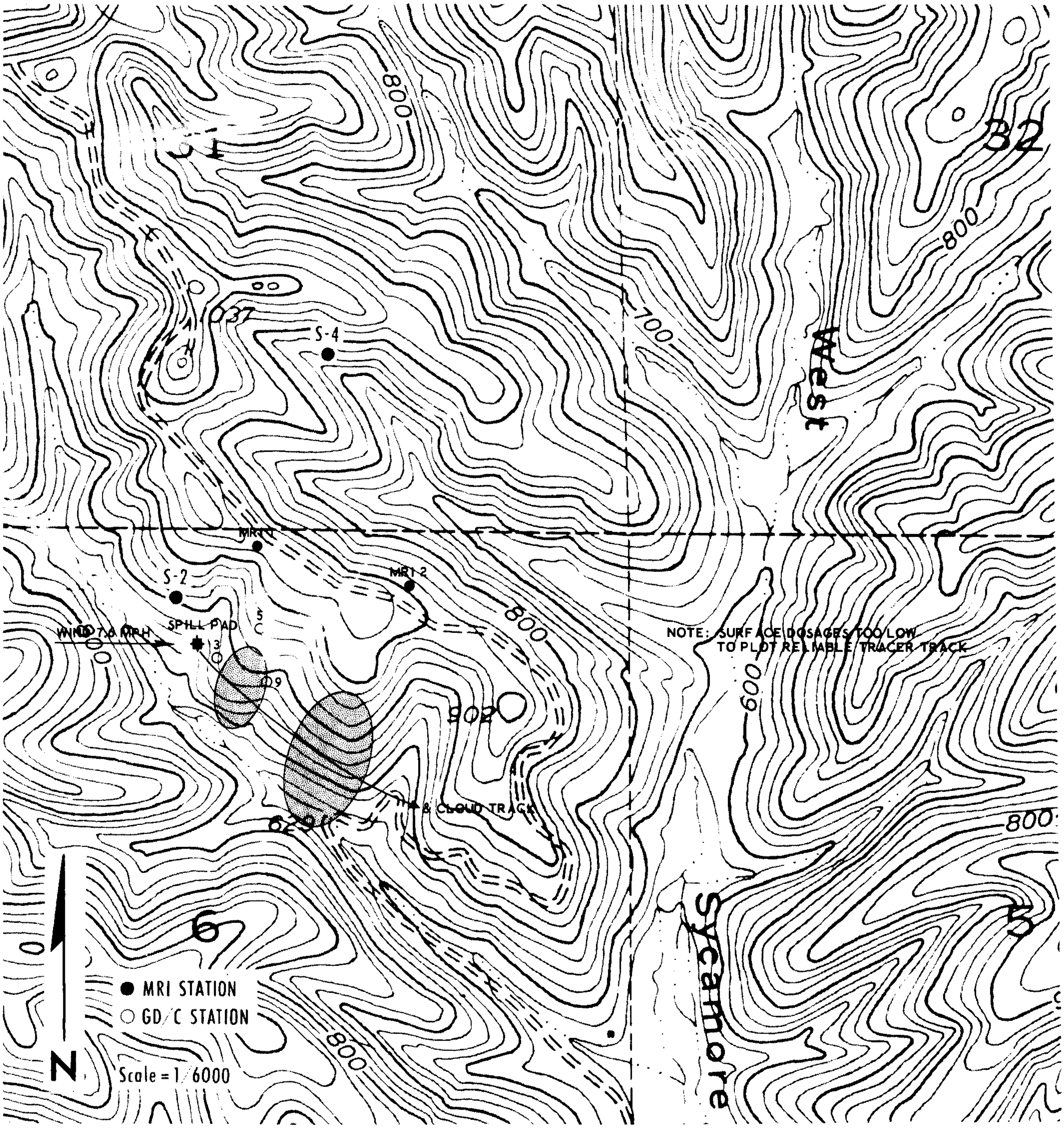
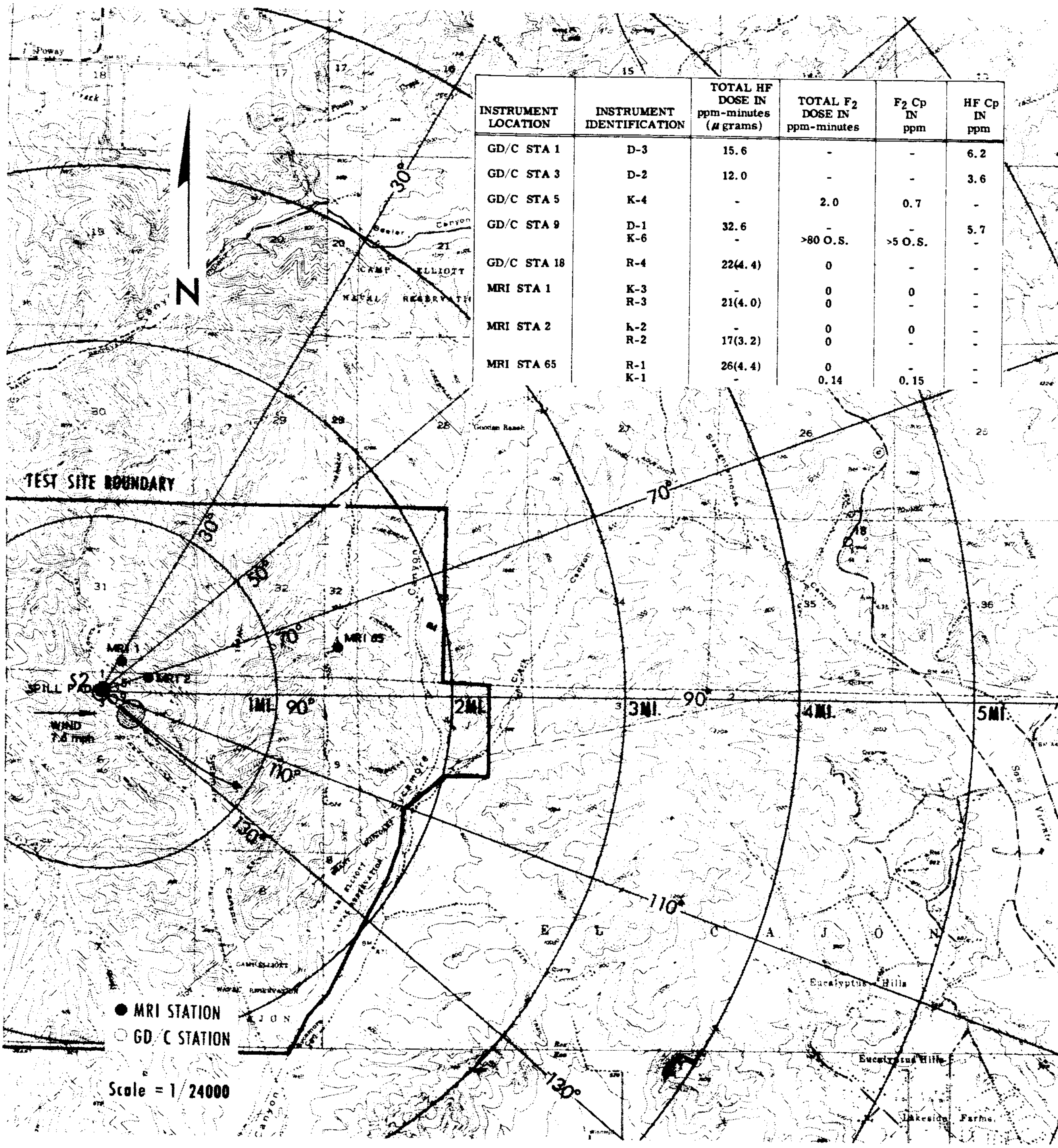


Figure 5-79. Test No. 26 Near Field F_2 and HF Concentration Data and Plume Trajectory



INSTRUMENT LOCATION	INSTRUMENT IDENTIFICATION	TOTAL HF DOSE IN ppm-minutes (μ grams)	TOTAL F_2 DOSE IN ppm-minutes	F_2 Cp IN ppm	HF Cp IN ppm
GD/C STA 1	D-3	15.6	-	-	6.2
GD/C STA 3	D-2	12.0	-	-	3.6
GD/C STA 5	K-4	-	2.0	0.7	-
GD/C STA 9	D-1 K-6	32.6 -	- >80 O.S.	- >5 O.S.	5.7 -
GD/C STA 18	R-4	22(4.4)	0	-	-
MRI STA 1	K-3 R-3	- 21(4.0)	0 0	0 -	- -
MRI STA 2	h-2 R-2	- 17(3.2)	0 0	0 -	- -
MRI STA 65	R-1 K-1	26(4.4) -	0 0.14	- 0.15	- -

Figure 5-80. Test No. 26 Far Field F_2 and HF Concentration Data and Plume Trajectory

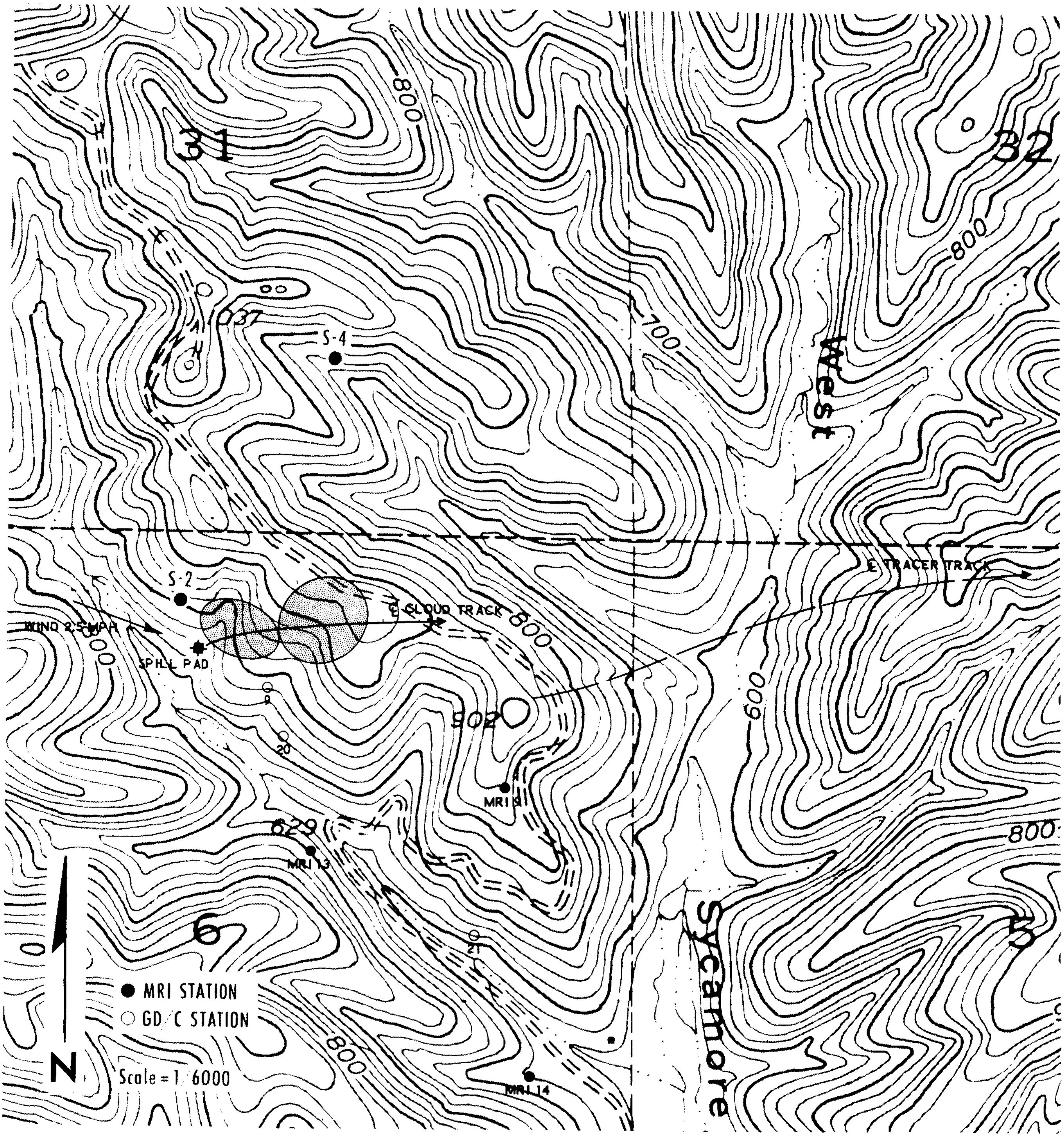
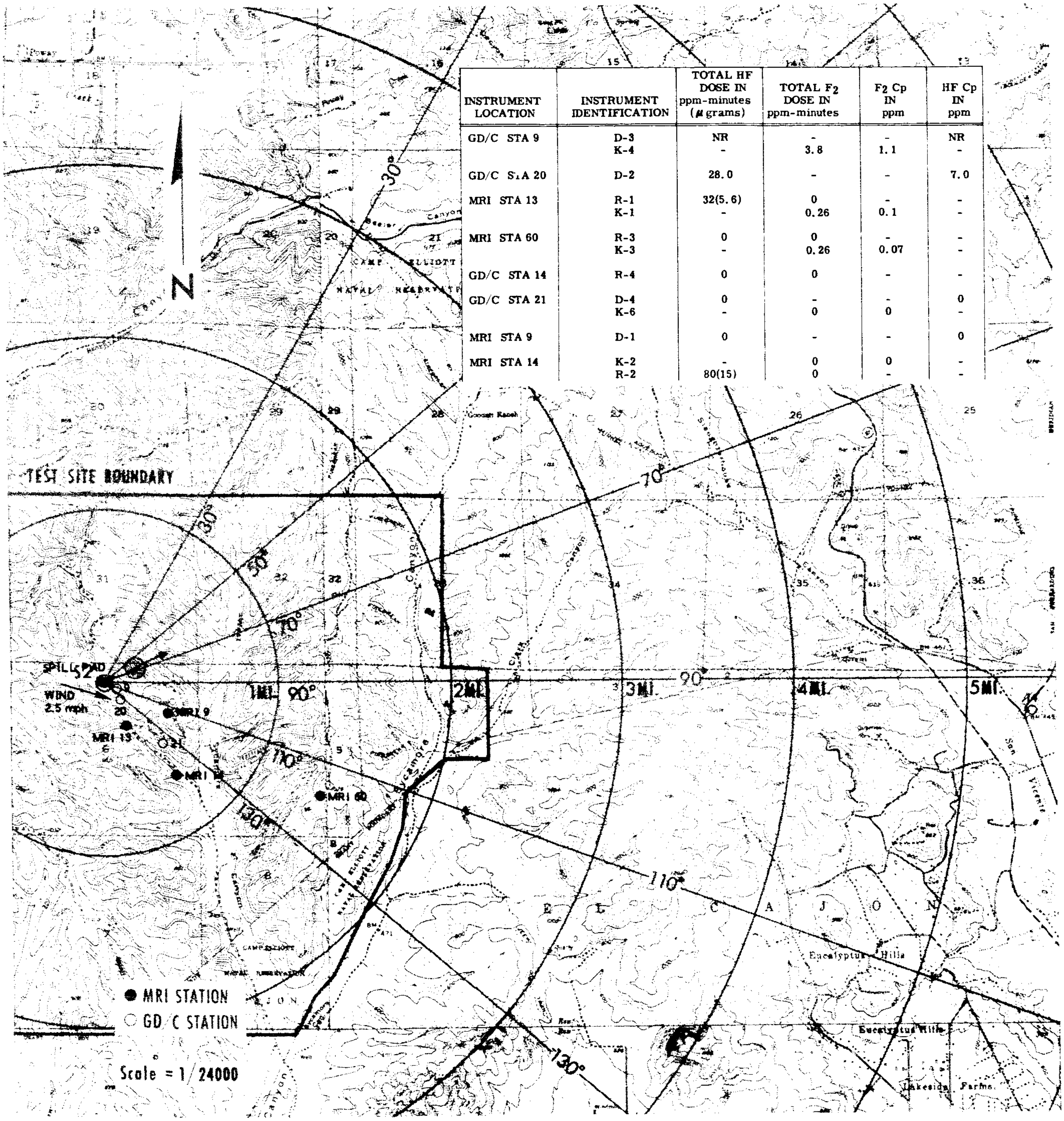


Figure 5-81. Test No. 27 Near Field F_2 and HF Concentration Data and Plume Trajectory



INSTRUMENT LOCATION	INSTRUMENT IDENTIFICATION	TOTAL HF DOSE IN ppm-minutes (μ grams)	TOTAL F_2 DOSE IN ppm-minutes	F_2 Cp IN ppm	HF Cp IN ppm
GD/C STA 9	D-3	NR	-	-	NR
	K-4	-	3.8	1.1	-
GD/C STA 20	D-2	28.0	-	-	7.0
MRI STA 13	R-1	32(5.6)	0	-	-
	K-1	-	0.26	0.1	-
MRI STA 60	R-3	0	0	-	-
	K-3	-	0.26	0.07	-
GD/C STA 14	R-4	0	0	-	-
GD/C STA 21	D-4	0	-	-	0
	K-6	-	0	0	-
MRI STA 9	D-1	0	-	-	0
MRI STA 14	K-2	-	0	0	-
	R-2	80(15)	0	-	-

Figure 5-82. Test No. 27 Far Field F_2 and HF Concentration Data and Plume Trajectory

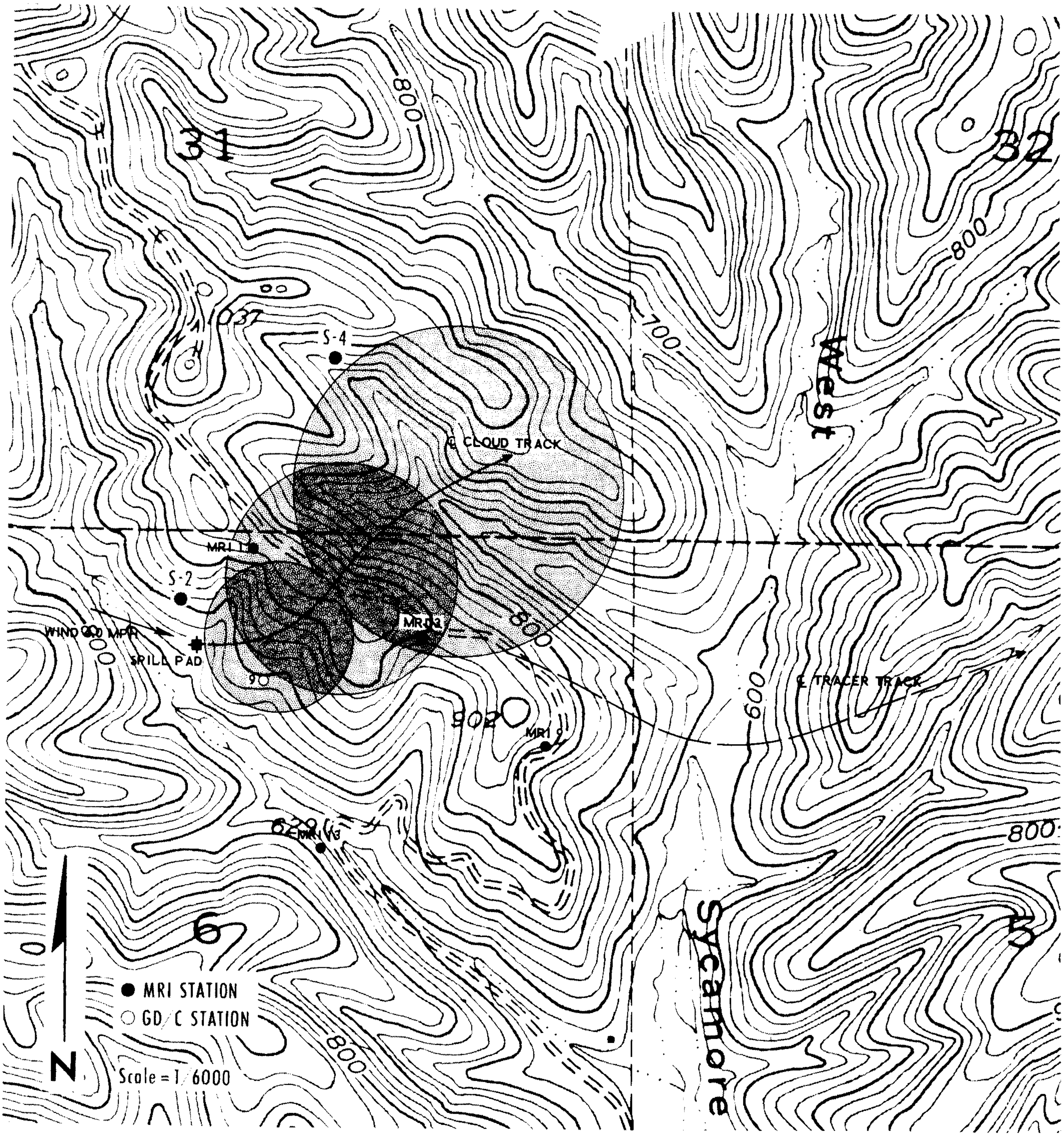
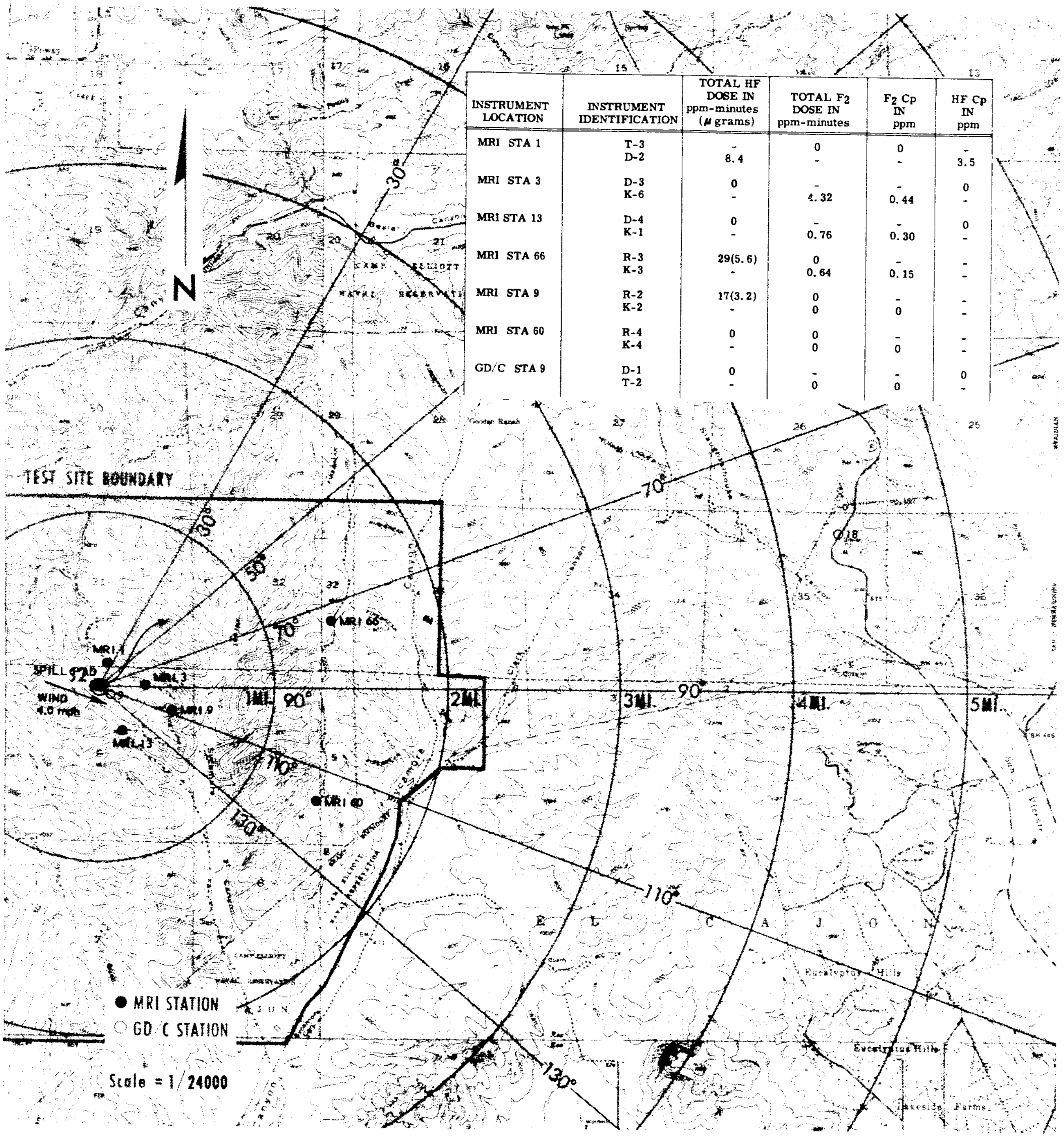


Figure 5-83. Test No. 28 Near Field F_2 and HF Concentration Data and Plume Trajectory



INSTRUMENT LOCATION	INSTRUMENT IDENTIFICATION	TOTAL HF DOSE IN ppm-minutes (μ grams)	TOTAL F_2 DOSE IN ppm-minutes	F_2 Cp IN ppm	HF Cp IN ppm
MRI STA 1	T-3	-	0	0	-
	D-2	8.4	-	-	3.5
MRI STA 3	D-3	0	-	-	0
	K-6	-	4.32	0.44	-
MRI STA 13	D-4	0	-	-	0
	K-1	-	0.76	0.30	-
MRI STA 66	R-3	29(5.6)	0	-	-
	K-3	-	0.64	0.15	-
MRI STA 9	R-2	17(3.2)	0	-	-
	K-2	-	0	0	-
MRI STA 60	R-4	0	0	-	-
	K-4	-	0	0	-
GD/C STA 9	D-1	0	-	-	0
	T-2	-	0	0	-

Figure 5-84. Test No. 28 Far Field F_2 and HF Concentration Data and Plume Trajectory

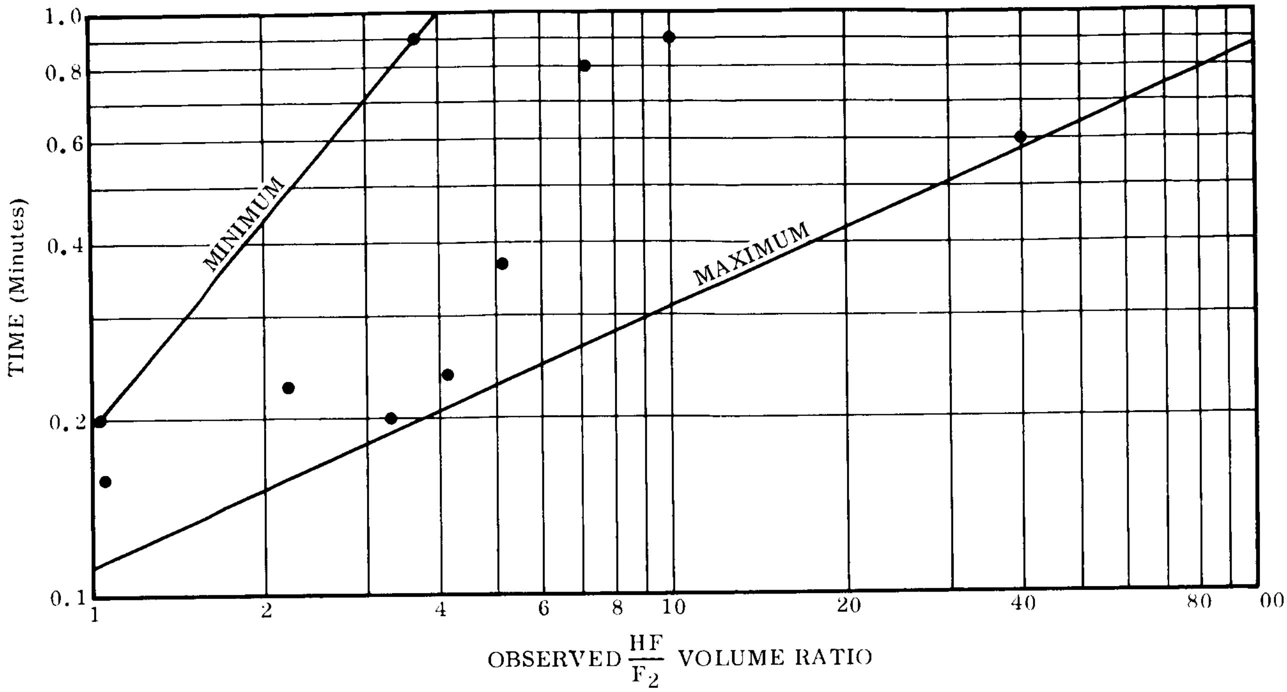


Figure 5-85. Range of Observed Conversion of F_2 to HF vs Time

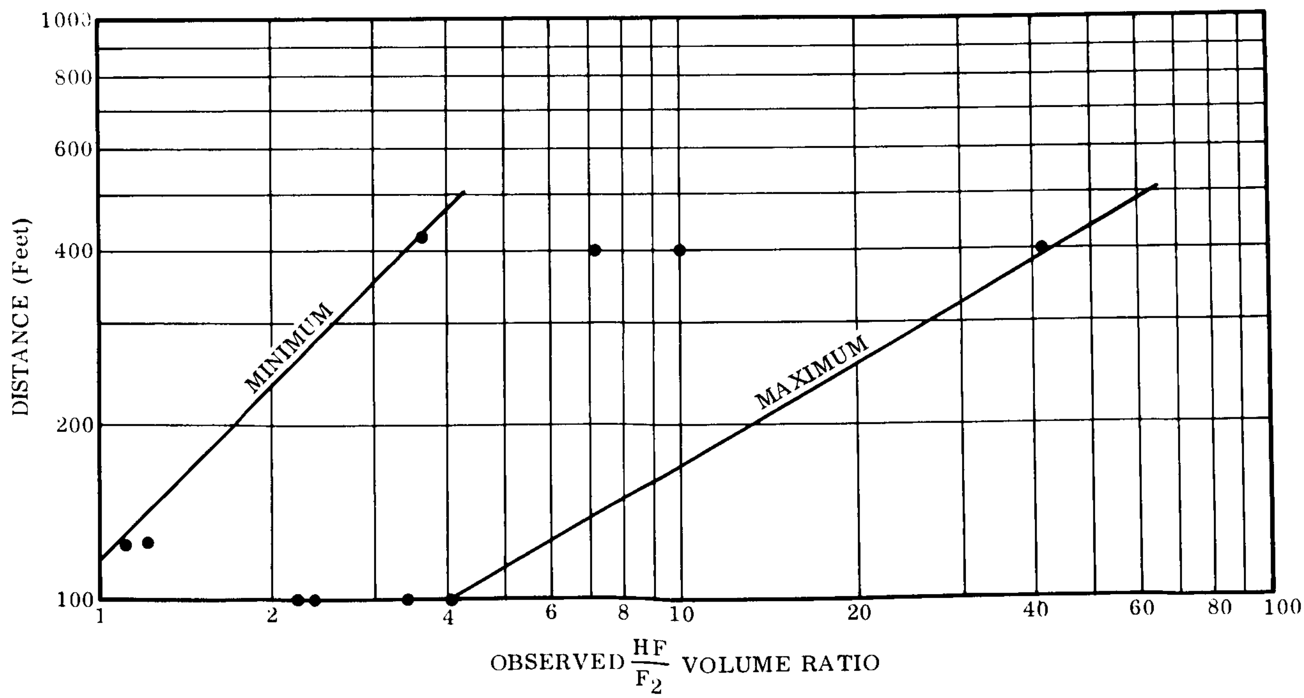


Figure 5-86. Range of Observed Conversion of F_2 to HF vs Distance

F. Soil and Water Fluorine Concentration Tests

Paragraph C (soil and water testing) of the Citation Permit was complied with by soil and water analysis before and after the release of fluorine. The initial set of samples was obtained in November 1963, prior to start of FLOX testing on NASA Contract NAS3-3228. This set comprised 31 soil samples and 2 water samples from the locations indicated in Figure 5-87. The soil samples were obtained from a depth one foot below surface level, and only that portion of the sample passing through a U. S. No. 16 screen was retained for analysis. The large number of samples was obtained to ensure that adequate representation of pre-FLOX testing soil samples would be available for later analysis. Of the 31 site samples, 6 were selected as being most likely to show any increase in fluoride concentration. The second and third sets of samples were obtained from these six locations only.

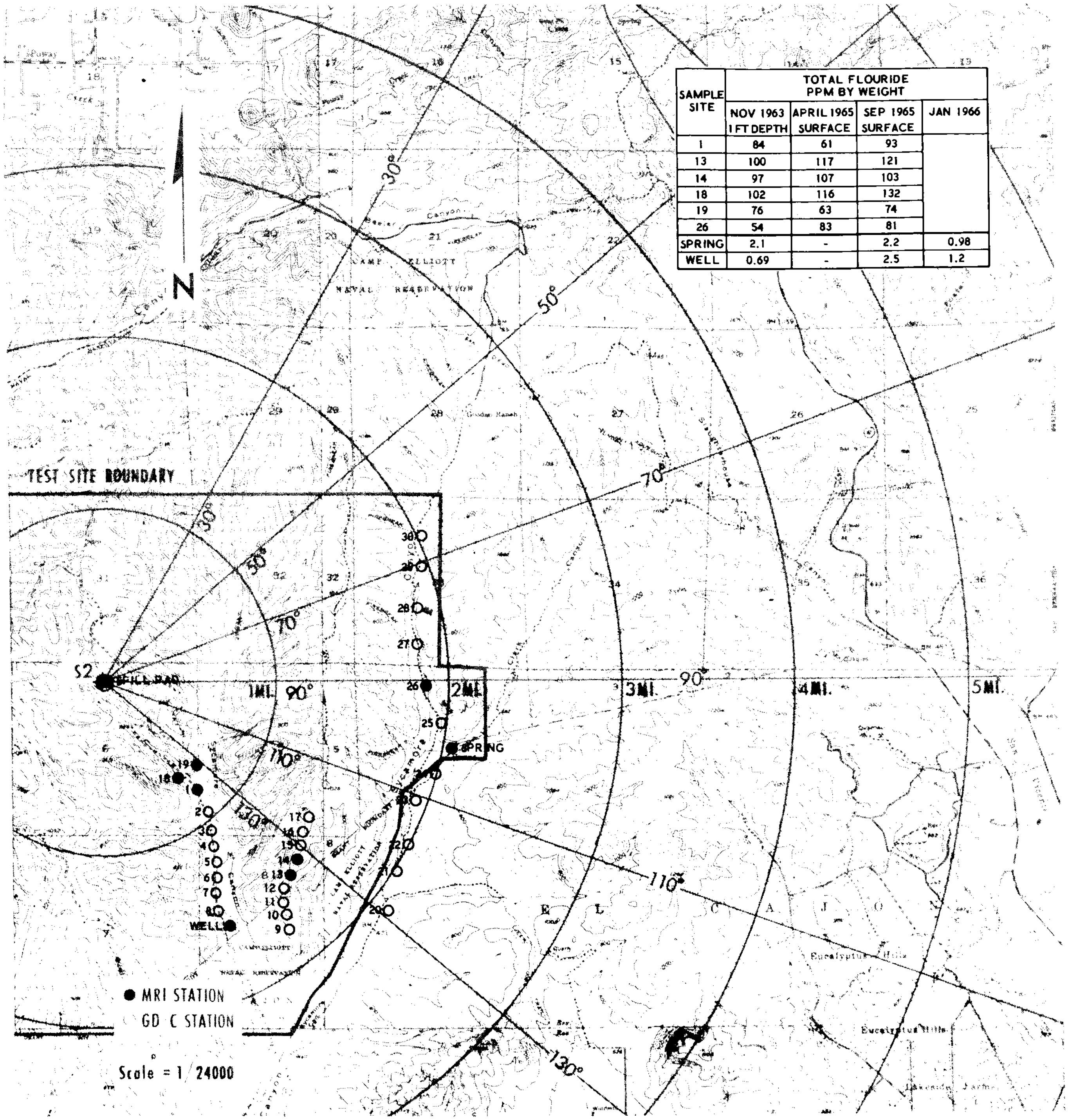
The second set of samples was obtained in April 1965, prior to start of FLOX testing, and the third set was obtained in September 1965 after completion of FLOX testing. These two sets of samples were taken from the soil surface (after removal of surface organic matter) rather than from one foot below surface level because the soil surface sample would be more apt to show a short-time fluoride buildup due to the low precipitation and low leaching rate in the area. Again, only that portion of the samples passing through a U.S. No. 16 screen was retained for analysis. The third set also included two water samples from the same locations sampled in the first set.

In compliance with the request of the San Diego Regional Water Pollution Control Board, a final water sample was obtained from the well location following normal seasonal precipitation and runoff in January 1966.

1. Soil and Water Analysis Procedure

Chemical analysis of the soil samples for fluoride required a preliminary fusion of the sample with alkali carbonate, followed by steam distillation of fluoride, as hexafluosilicic acid, from the dissolved melt. The fluoride concentration of the distillate was determined colorimetrically, using known sodium fluoride solutions as standards. Chemical analysis of the water samples was performed by the same procedure, except that the samples were distilled directly, without the preliminary fusions. The detailed procedure for the soil analysis is described in succeeding paragraphs.

The collected soil sample is spread on a polyethylene sheet and allowed to air dry at ambient temperature and humidity (approximately $70^{\circ}F$ and 65 percent RH). A 3g aliquot is obtained from the sample by

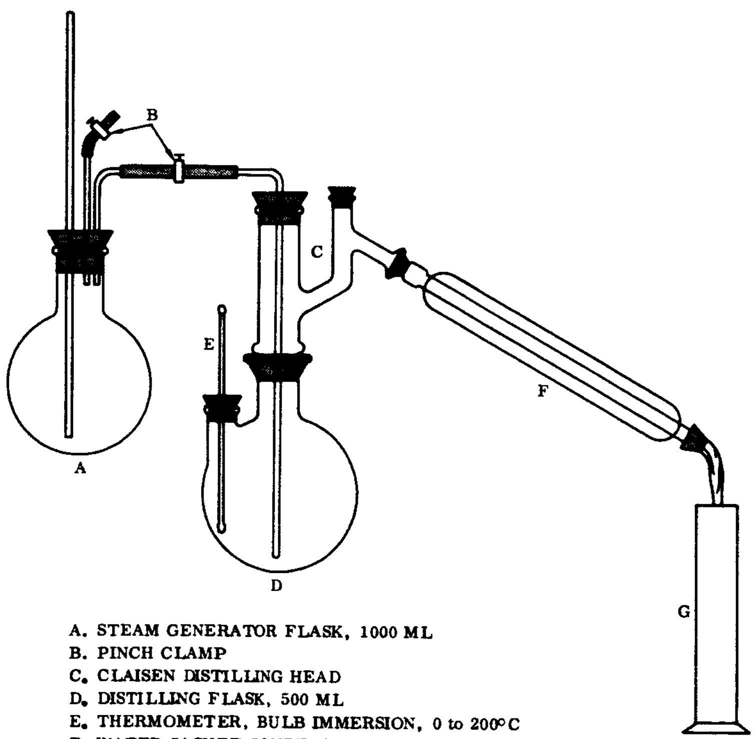


SAMPLE SITE	TOTAL FLOURIDE PPM BY WEIGHT			
	NOV 1963 1 FT DEPTH	APRIL 1965 SURFACE	SEP 1965 SURFACE	JAN 1966
1	84	61	93	
13	100	117	121	
14	97	107	103	
18	102	116	132	
19	76	63	74	
26	54	83	81	
SPRING	2.1	-	2.2	0.98
WELL	0.69	-	2.5	1.2

Figure 5-87. Soil and Water Analysis and Sample Location

coning and quartering, and weighed into a platinum crucible. Three grams each of sodium carbonate and potassium carbonate are added to the crucible, and the mass is melted first over a Meeker burner and finally in an electric furnace for 4 hr at 1000°C. The melt is cooled in a desiccator, transferred to a 500 ml two-necked distilling flask, and dissolved in 75 ml of deionized water.

The distilling flask is connected to the steam generator and condenser as shown in Figure 5-88. To the distilling flask are added 1g of silver oxide powder, five or six soft glass beads, and a mixture of 35 ml of 85 percent phosphoric acid and 35 ml of 96 percent sulfuric acid. The distilling flask is heated until the temperature reaches 155°C at which time the pinch clamp is removed from the steam inlet tube and placed on the steam relief tube of the steam generator. By controlling the heat to the steam generator and to the distillation flask, the sample solution volume is maintained at about 75 ml and the temperature at 155°C. The steam distillation is continued until 200 ml of distillate is collected.



A. STEAM GENERATOR FLASK, 1000 ML
B. PINCH CLAMP
C. CLAISEN DISTILLING HEAD
D. DISTILLING FLASK, 500 ML
E. THERMOMETER, BULB IMMERSION, 0 to 200°C
F. WATER JACKET CONDENSER
G. GRADUATED CYLINDER, POLYPROPYLENE, 250 ML

Figure 5-88. Distillation Apparatus

A 50 ml aliquot of the distillate is treated with 5.0 ml of 1.8g per liter of Eriochrome Cyanine R in deionized water and with 5.0 ml of 0.265g per liter of zirconyl chloride octahydrate in 70 percent (by volume) concentrated hydrochloric acid. The color intensity is read on a Beckman Model DU spectrophotometer at 5275 Å using a 1 cm path-length sample cell. The spectrophotometer is zeroed against a reference solution of 10.0 ml of the Eriochrome Cyanine R solution dissolved in 110 ml of 7 percent (by volume) concentrated hydrochloric acid. Standard sodium fluoride solutions are prepared containing 40 to 2000 μg fluoride per liter, and 50 ml aliquots of these are treated in the same manner as the sample distillate aliquots. From the measured color intensity of the standards, a calibration curve is plotted showing absorbance versus micrograms fluoride. The weight of fluoride present in the sample distillate aliquot is read from the calibration curve, and the concentration of fluoride in the soil sample is calculated in parts per million by weight.

2. Results

The concentrations of fluoride found for the six soil sample sites and two water sample sites are shown in Figure 5-87. The total fluorine and fluoride pollutant load on the sampled area between April 1965 and September 1965 was 9700 lb, and between November 1963 and September 1965, including this program, it was 16,150 lb. Examination of the data for the two sets of soil surface samples (April and September 1965) and the two sets of water samples shows only two sites with significant absolute or percentage increases in fluoride concentration. These are soil sample site 1 and the well water site. However, both of these sites are directly adjacent to the stream bed which drains West Sycamore Canyon, and as such would be expected to show a fluoride accumulation from precipitation runoff from the surrounding hillsides.

Miramar Naval Air Station records show that the total precipitation for the period from the first FLOX spill to collection of the third set of samples was 0.30 inch, of which 0.20 inch occurred after the last FLOX spill test. This amount of rainfall is not sufficient to cause large scale runoff into the general drainage system of the area, but would cause some accumulation in local low areas. The rainfall data, therefore, support the assumptions made concerning the fluoride increases found from soil sample site 1 and the well water site.

In a study of the fluoride concentration of surface soils, Robinson and Edgington (Reference 7) analyzed 137 samples from depth profiles of 30 sites from 25 states of the continental U.S. One of these samples was a Redding clay loam from San Diego County. Analysis of this sample showed a fluoride concentration of 85 ppm at 0 to 7 inches depth, increasing to 154 ppm at 41 to 51 inches depth. The fluoride concentration for the 30 sites ranged from a low of 12 ppm to a high of 7070 ppm. The average for the surface layers, to approximately "plow depth," was 292 ppm. The fluoride concentrations found for the Sycamore Canyon soil samples, therefore, fall within the expected range, and the correlation with the San Diego Country sample analyzed in the referenced study is quite good.

The concentration of fluoride in drinking waters falls mainly in the range of 0.05 to 1.0 ppm (Reference 8). The fluoride concentrations found for both spring water samples and the second well water sample are somewhat higher than this. However, in the analysis procedure the water samples were not filtered, but the sample aliquot for analysis was decanted from the gross sample. Any suspended matter present may have contributed a significant portion of the fluoride found, especially since the colloid portion of soils contains the major part of the soil fluoride content.

It may be concluded that the increase in the fluoride content of the soil and water in the test area did not present a health hazard.

G. Blast Measurement of FLOX - Fuel Reaction

During the eleven combustive spill tests, overpressure instrumentation was active to document the overpressure profile of the reaction between the LF_2/LO_2 mixtures with charcoal and RP-1 fuels. Since both of these fuels react hypergolically with a 30 percent LF_2/70 percent LO_2 mixture, no significant overpressure was expected under the test conditions, although no test data was available to verify this expectation. Blast criteria documentation for DOD siting criteria (Reference 9) specify the same criteria for LF_2 as they do for LO_2.

Overpressure measurements were made with Kistler transducers and associated support structure, charge amplifiers, connecting cables, and a photo recording oscilloscope located in the control room. All input equipment was furnished on loan by USAF Rocket Propulsion Laboratory Hazards Analysis Branch and installed with their technical assistance. All data recorded was similar in that a pressure spike of about 0.25 psig magnitude occurred at detonation followed by lower magnitude pulses for 20 to 50 ms as shown in Figure 5-89. Since initiation of each combustive spill was accomplished by a shaped charge, a calibration test was conducted to measure the overpressure due to the shaped charge alone. The trace of this test is shown in Figure 5-90. It is apparent that the initial spike in Figure 5-89 is the shaped charge detonation shown in Figure 5-90, and that there is no significant overpressure from the LF_2/LO_2 fuel reaction.

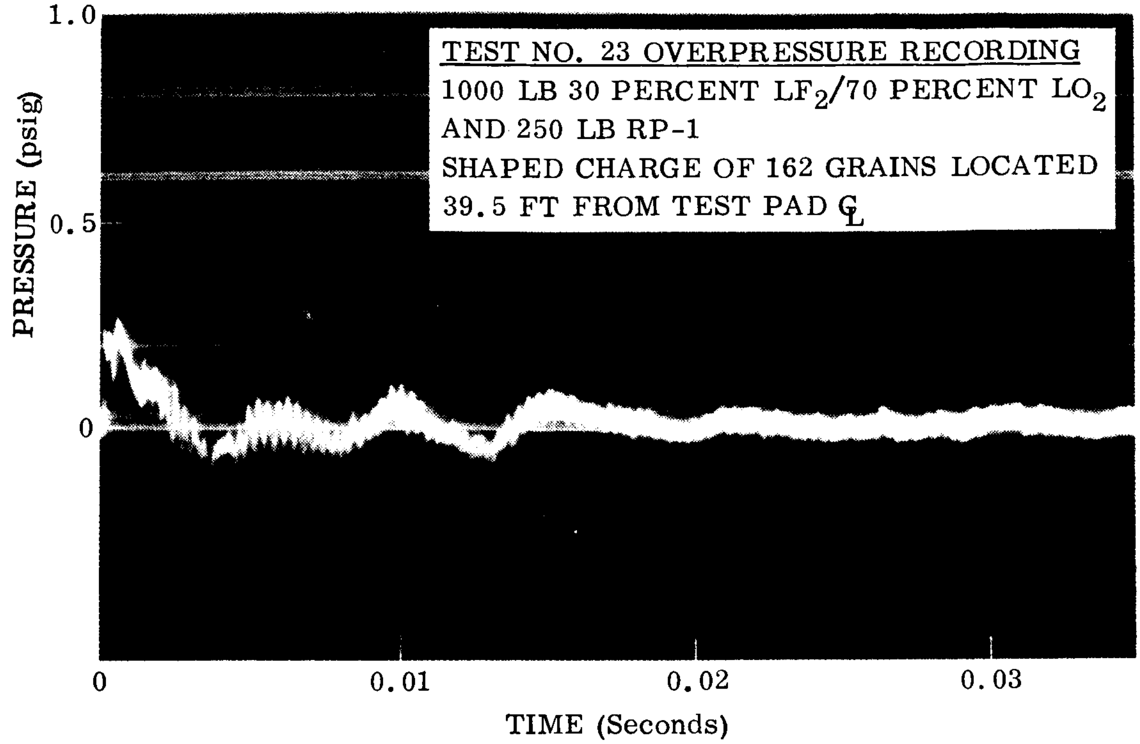


Figure 5-89. Test No. 23 Overpressure Recording

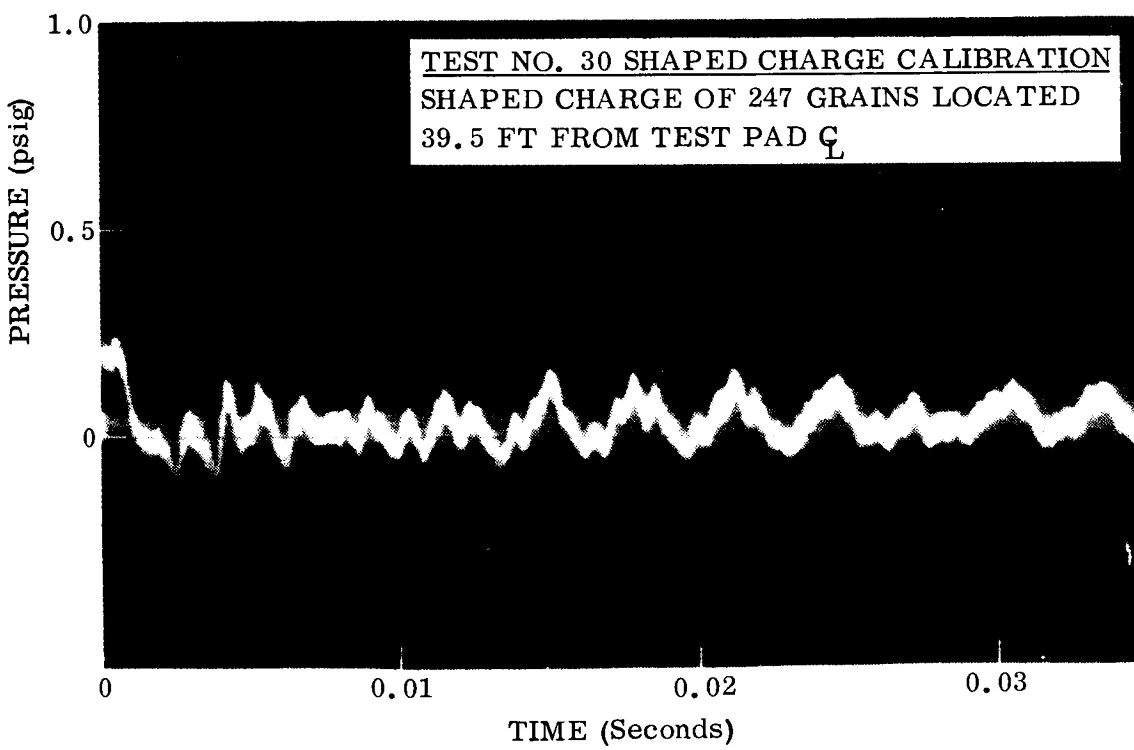


Figure 5-90. Test No. 30 Shaped Charge Calibration

VI. APPLICATION OF TEST RESULTS TO THE DETERMINATION OF THE CAPABILITY OF SYCAMORE TEST SITE FOR FLUORINE TESTING

Sycamore Test Site fluorine testing capability was determined by: (1) defining the pollutant source created by operational and catastrophic releases of fluorine, (2) defining the diffusion characteristics of the Sycamore area, (3) applying the NASA F_2 and HF dose limits in the derived diffusion model.

A. Basis for Conclusions

The conclusions to be drawn from this program are based on the constraints prevailing at this time. These constraints, and hence the conclusions, are subject to change. The most variable constraints and the effect each has on conclusions are listed below and discussed in the following paragraphs.

1. Variable Constraints

   a. Allowable threshold limit values for fluorine and hydrogen fluoride.

   b. Hydrolysis of fluorine to hydrogen fluoride.

   c. Future use of adjoining property to the east (downwind) from Sycamore Test Site.

2. Effect of Threshold Limit Values for Fluorine and Hydrogen Fluoride

The conclusions are based on the Threshold Limit Values established in the NASA Citation Permit and Site Approval, which was issued specifically for the program. The values specified in paragraph 3 of the Citation Permit are assumed to be the boundary conditions that were not to be exceeded. These values are applicable to the Sycamore Test Site Boundary shown in Figure 2-1, or approximately 2 miles east of S-2. (Azimuths other than 30 to 130 degrees are of no practical interest for various operational reasons.)

The limits set forth in paragraph 3 of the Citation Permit are based on the most widely accepted toxicity values for fluorine. Substantiating data on animal and human exposure to F_2 is less than that for many more widely used propellants; however, a NASA program (nearly completed at the time of this writing) will provide additional data on the toxic exposure limits and may result in changes to the above limits.

Since the quantity of fluorine that may be released at the source is directly proportioned to the allowable peak concentration at the boundary, any revision of the values used above would require revision of the maximum permissible credible release.

3. Effect of Hydrolysis of Fluorine to Hydrogen Fluoride

As discussed in Section V, there is considerable evidence that fluorine hydrolyzes to hydrogen fluoride in the atmosphere. The rate at which this occurs and the necessary attendant atmospheric conditions have not been fully defined, and there is a need for further experimental work. Since the allowable concentration of HF (at the present time) is 10 times that of elemental fluorine, and since the quantity of fluorine that may be released at the source is directly proportional to the allowable peak concentration, a potential increase of 10 times in permissible release of fluorine is apparent if hydrolysis is complete within the boundary.

4. Future Use of Adjoining Property

As illustrated in Figure 2-1, the property extending 2 miles eastward from the east boundary of Sycamore Test Site is an unoccupied area accessible by foot or trail vehicles. Until this area is developed, it represents a buffer zone that may be used to increase confidence in the validity of the limitations established. It could also be used as a boundary extension to increase limitations if required; precedents have been established by such arrangements in the vicinity of other test sites. The quantity of permissible fluorine release is approximately proportional to the square of the distance to the boundary. Use of this area, therefore, could provide an additional confidence factor of 4 on predicted peak concentration, or increase the quantity of fluorine to be released by a factor of 4.

B. Source Considerations

The sources of significant pollutants from a fluorine static test program fall into three types of credible occurrences defined as follows.

Type-I Credible Occurrence: An accident resulting in the rupture of a transfer line during transfer of LF_2.

Type II Credible Occurrence: An accident resulting in a conflagration of a fully tanked static test vehicle.

Type III Credible Occurrence: A normal firing of an engine system resulting in a source of hot HF from the engine exhaust at ground level.

Other modes of release, regardless of credibility, are comparatively minor to the above in frequency of occurrence or quantity of emission. A massive spill from a storage tank is not considered credible because it is stationary, high integrity equipment and less susceptible to damage than a transport trailer for which no restrictions exist.

C. Frequency and Duration of Credible Occurrences

It is assumed that a fluorine development program of two years duration is planned which requires the development testing associated with a complete vehicle propulsion and propellant system including tanking, detanking, and static firing. The frequency of credible occurrences is

TYPE	NUMBER OF OCCURRENCES	DURATION
I	3	5 minutes each cloud pass
II	1	10 minutes each cloud pass
III	75	20 to 350 seconds each firing

D. Source Quantities

It is assumed that there are four programs for which the Sycamore Test Site might be considered for vehicle development static testing. In the order of decreasing quantity of fluorine on site they are: 1) a 30-percent FLOX Atlas, 2) a 50-percent FLOX Atlas, sustainer engine only, 3) a fluorine-hydrogen high energy upper stage of Centaur size, and 4) a hydrogen-fluorine kick stage. The quantities of fluorine and hydrogen fluoride which represent potential pollution loads for diffusion in the Sycamore downwind area are shown below.

1. Thirty Percent FLOX Atlas

Type I — 1375 lb F_2 at an oxidizer transfer rate of 1000 gpm with automatic shutdown 30 seconds after break.

Type II — 14,000 lb F_2 and 41,000 lb HF resulting from conflagration of 55, 000 lb LF_2 with 75 percent combustion (estimated). Eighty percent of the surviving F_2 hydrolyzes to HF resulting in 52, 200 lb of HF and 2800 lb of F_2.

Type III 310 lb/sec HF for 130 seconds.
61 lb/sec HF for 290 seconds. (Reference 10)

2. Fifty Percent FLOX Atlas, Sustainer Only

Type I 1375 lb F_2 at an oxidizer transfer rate of 1000 gpm.

Type II 7500 lb F_2 and 22, 000 lb HF resulting from conflagration of 30,000 lb LF_2 with 75 percent combustion (estimated). Eighty percent of the surviving F_2 hydrolyzes to HF resulting in 28, 100 lb of HF and 1900 lb of F_2.

Type III 61 lb/sec HF for 290 seconds (Reference 10)

3. Hydrogen-Fluorine Centaur

Type I 1270 lb F_2 at an oxidizer transfer rate of 200 gpm with automatic shutdown 30 seconds after break.

Type II 8000 lb F_2, 24,000 lb HF resulting from conflagration and hydrolysis of 32,000 lb LF_2 with 75 percent combustion (estimated). Eighty percent of the surviving F_2 hydrolyzes to HF resulting in 30,400 lb of HF and 1600 lb of F_2.

Type III 60.8/sec HF for 400 seconds. (Reference 10)

4. Hydrogen-Fluorine Kick Stage

Type I 1270 lb F_2 at an oxidizer transfer rate of 200 gpm with automatic shutdown 30 seconds after break.

Type II 1500 lb F_2 and 4700 lb HF resulting from conflagration of 6000 lb F_2 with 75 percent combustion (estimated). Eighty percent of the surviving F_2 hydrolyzes to HF resulting in 5900 lb of HF and 300 lb of F_2.

Type III 20 lb/sec HF for 350 seconds. (Reference 10)

E. Diffusion Prediction

Without diffusion tests in a given area, the WIND equation, which relates downwind concentration or dose to source strength, distance, and near-surface stability parameters, is probably the best approximation. The WIND equation was derived experimentally from tests in reasonably flat terrain, but is sometimes used with modification at sites where no experimental data are available. The equation is restricted for use with a continuous ground level source, and predicts the peak concentration on a crosswind section through the plume at a distance, X, from the source.

The Sycamore diffusion tests determined the order of variation with the WIND prediction for cold and hot sources and the surface location of the plume trajectory. No attempt was made to determine longitudinal or crosswind distribution. To aid in this objective, redundancy was provided by visual smoke tracking with aerial and ground cameras and the use of fluorine and hydrogen fluoride sensing instruments.

The results of the work done indicate improved dilution at Sycamore over WIND predictions by a factor of 10, and no significant difference at the boundary between the dilution of a cold or a hot source. The predicted boundary doses for F_2 and HF are:

90 percent of doses will be under 0.33 ppm-min per 100 lb F_2

50 percent of doses will be under 0.08 ppm-min per 100 lb F_2

90 percent of doses will be under 0.66 ppm-min per 100 lb HF

50 percent of doses will be under 0.16 ppm-min per 100 lb HF

F. Maximum Permissible Operations

Based on the above predicted dosages and the allowable NASA limits discussed in Section II of 5 ppm-min for F_2 and 50 ppm-min for HF, the quantities of fluorine and hydrogen fluoride that can be tolerated in an accidental or intentional release at Sycamore Test Site are:

1500 lb F_2 or 7500 lb HF for 90 percent criterion

6200 lb F_2 or 30,000 lb HF for 50 percent criterion

Representative fluorine programs that could be conducted at Sycamore within the NASA-imposed boundary dosage limits are shown in the following table.

Table 6-1. Sycamore Test Site Fluorine Testing Limitations

PROGRAM	NASA LIMIT AT 2-MILE BOUNDARY* (Percent)	OPERATIONAL CONDITIONS: FLIGHT WEIGHT TANKING (Percent full)	OPERATIONAL CONDITIONS: ENGINE FIRING DURATION (Seconds)
1. Full Scale, Atlas 30 percent FLOX	90	14.5	24
	50	60	100
2. Full Scale, Atlas Sustainer Only, 50 percent FLOX	90	27	125
	50	100	300
3. Hydrogen-Fluorine, Centaur	90	25	115
	50	100	470
4. Hydrogen-Fluorine, Kick Stage 10,000 lb Thrust 7000 lb $H_2 + F_2$	90	100	350
	50	100	350

*90 percent criterion denotes 90 percent of doses at the boundary are below allowable.

50 percent criterion denotes 50 percent of doses at the boundary are below allowable.

G. Constraints

The limitations of Sycamore Test Site for fluorine testing are determined by the exposure values for inhalation imposed by NASA, namely:

Fluorine: 5 ppm-min each exposure or 201.6 ppm-min/14 days.

Hydrogen Fluoride: 50 ppm-min each exposure or 604.8 ppm-min/14 days.

Additional limitations which are inherent and fixed are the exclusion distance available between the release point and the property boundary, the rate of hydrolysis of fluorine to the less toxic hydrogen fluoride, and the climatology of the area.

Taking the foregoing limitations into consideration, the following constraints would be imposed on a fluorine test program:

1. Two-mile exclusion distance to property boundary in the easterly sector.

2. Inversion height 1500 ft or higher.

3. Wind 2.5 mph or higher from the quadrant between southwest and northwest.

4. Daylight operation between 10 a.m. and 4 p.m.

5. Scattered to clear sky condition permitting insolation of the earth's surface.

6. Fuel on board vehicle tanks prior to oxidizer tanking.

7. 75 percent conversion of F_2 to HF in conflagration with RP-1.

8. Containment of oxidizer assured or oxidizer spill preventable in non-combustive spill.

9. Assume hydrolysis of fluorine to hydrogen fluoride is 80 percent completed at the 2-mile boundary. Referring to Figure 5-86, "Minimum" line at the 500 ft distance, the observed HF/F_2 volume ratio is 4/1, i.e., 4 parts of HF from the release of 5 parts of F_2, or 80 percent conversion. Since this is the limit of observed values it is applied at the 2-mile boundary, although the actual conversion probably would be completed within the boundary.

10. Not more than 12 operations equivalent to the above to be conducted in any consecutive 14-day period (Citation Permit Cumulative Dose Criteria).

VII REFERENCES

1 Air Force Cambridge Research Laboratory, The Ocean Breeze and Dry Gulch Diffusion Programs, Report No. AF CRL-63-791 (11), December 1963.

2 Convair Division of General Dynamics, Feasibility Testing 30 Percent FLOX with Atlas Oxidizer System Components, Report No. GDA-BGM64-002, July 1964.

3 Convair letter dated 19 May 1965 to San Diego Department of Public Health, and copy of this letter countersigned on 2 June 1965 by J. B. Askew, M.D.

4 Convair letter dated 20 May 1965 to San Diego Water Pollution Control Board.

5 San Diego Water Pollution Control Board letter dated 28 May 1965 to Convair.

6 National Aeronautics and Space Administration, Rate of Reaction of Gaseous Fluorine with Water Vapor at 35°C, NASA Report NACA TN4374, September 1958.

7 Robinson, W. O. and Edgington, G., "Fluorine in Soils," Soil Science 61: p 431-353, 1946.

8 Nichols, M. S., "Occurrence and Treatment of Fluoride Waters," American Journal of Public Health, 29:p991-998, 1939.

9 Department of Defense, Quantity-Distance Storage Criteria for Liquid Propellants, Report No. DOD 4145.21, March 1964.

10 Convair Division of General Dynamics, Study of High Energy Propellants, Report No. GDC-EER-AN-731, April 1965.

APPENDIX I

CALIBRATION PROCEDURE 00520

GD/C ELECTRONIC FLUORINE DETECTOR

MODEL 00510

CALIBRATION PROCEDURE

GD/C ELECTRONIC FLUORINE DETECTOR

MODEL 00510

REPORT NO. FLOX-00520

FLOX

PREPARED BY: D. A. Rau

APPROVED BY: W. M. Gross

CHECKED BY R. L. Barrows

APPROVED BY: J. R. Thayer

APPROVED BY: [illegible signature]

FLOX
RELEASED
DATE
CHG. LETTER —

I. SCOPE

This document describes the calibration requirements and procedure for the GD/C Electronic Fluorine Detector, Model 00510. This document is written for use in the Atmospheric Diffusion Control of FLOX and HF at Sycamore test program (NAS-3245). Applicability of this procedure to other test programs shall be determined by the cognizant program office.

II. MATERIALS AND INSTRUMENTATION REQUIREMENTS

A. Fluorine Standard

A cylinder of air containing 5 to 50 ppm by volume of fluorine is required. The fluorine concentration is determined by absorbing a measured volume of the fluorine standard in 1% potassium iodide solution. The solution is then analyzed for fluoride by the colorimetric analysis given in FLOX Procedure 00521 Paragraph III.D.3.

B. Flowmeter

A flowmeter calibrated for the range of 100 to 500 cubic centimeters per minute is required to calibrate the instrument pump flowrate.

C. Timer

A calibrated timer which indicates seconds elapsed time from start is required. The timer shall have a minimum capacity of 300 seconds.

D. Absorption Cylinder

The absorption cylinder is a 250 milliliter polypropylene graduated cylinder, equipped with a 2-hole rubber stopper, cap. The inlet and outlet tubes of the cylinder are polytetrafluoroethylene tubing.

III. PROCEDURE

A. Pump Flowrate

Connect the flowmeter outlet to the inlet of the instrument. Start the pump and allow it to run for five minutes. Read and record the flowmeter reading.

B. Instrument Sensitivity

1. Fluorine Standard Calibration

Connect the fluorine standard to the flowmeter inlet. Connect the flowmeter outlet to the inlet tube of the

III. PROCEDURE (Continued)

absorption cylinder, but do not place the tube in the absorption cylinder (Figure 1.). Open the fluorine standard cylinder valve and adjust the flowrate to 250 cubic centimeters per minute. Fill the absorption cylinder with 100 milliliters of 1% potassium iodide solution. Place the absorption cylinder inlet tube into the absorption cylinder and immediately start the timer (Figure 2.). Record the initial flowmeter reading and at one minute intervals. After five minutes turn off the fluorine standard cylinder valve, and disconnect the apparatus. Calculate the volume, in cubic centimeters, of fluorine standard passed through the potassium iodide solution.

Determine the weight of fluoride absorbed in the potassium iodide solution by the colorimetric analysis for fluoride given in FLOX Procedure 00521, Paragraph III.D.3. Finally, calculate the fluorine concentration of the fluorine standard in parts per million by volume. The calculation is:

ppm F_2 by volume = (milligrams fluoride absorbed x 5.9×10^5) ÷ (cubic centimeters of fluorine standard).

2. Instrument Calibration

Turn on the instrument and recorder. Adjust the recorder pen position to the chart zero line with the recorder zero control. Connect the fluorine standard to the flowmeter inlet and the flowmeter outlet to the instrument inlet (Figure 3.). Open the fluorine standard cylinder valve until the flowmeter reading equals that found in the pump flowrate calibration, Paragraph III.A. Continue the fluorine standard flow until the recorder indicates a steady reading. Turn off the fluorine standard, the instrument and recorder, and disconnect the apparatus. From the fluorine concentration of the fluorine standard and the recorder output calculate the instrument sensitivity in units of ppm fluorine by volume per recorder scale division.

3. Fluorine Standard Recalibration

If two or more instruments are to be calibrated from the same fluorine standard, it is necessary to determine the fluorine concentration of the fluorine standard only before and after the entire instrument calibration run. However, do not use more than 25% by volume of the fluorine standard between calibrations; this is to minimize effects of fluorine release from the fluorine standard cylinder walls.

IV. FREQUENCY AND SIGN-OFF REQUIREMENTS

A. Frequency

Each instrument shall be calibrated prior to initial use. Thereafter, each instrument shall be calibrated after each three test runs or 15 hours running time, whichever occurs first.

B. Sign-off

A calibration record shall be maintained for each instrument (Figure 4.). The record shall include the calibration procedure number, instrument model and serial numbers, calibration data obtained, date of calibration, and signature of the of the person performing the calibration.

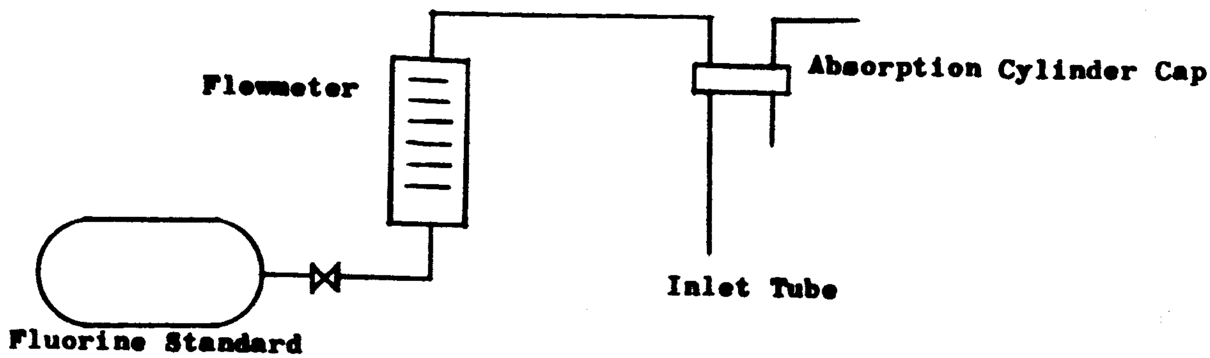


FIGURE 1. FLUORINE STANDARD CALIBRATION, FLOWRATE ADJUSTMENT

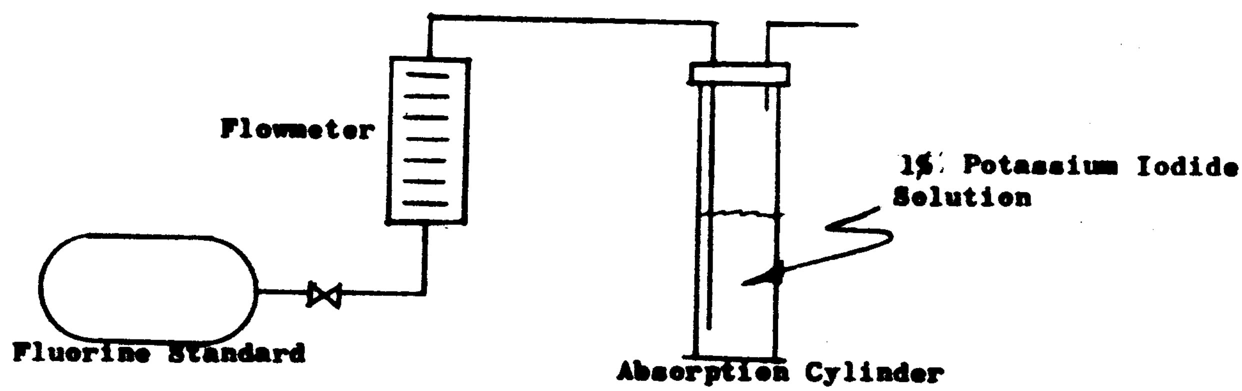


FIGURE 2. FLUORINE STANDARD CALIBRATION, FLUORINE ABSORPTION

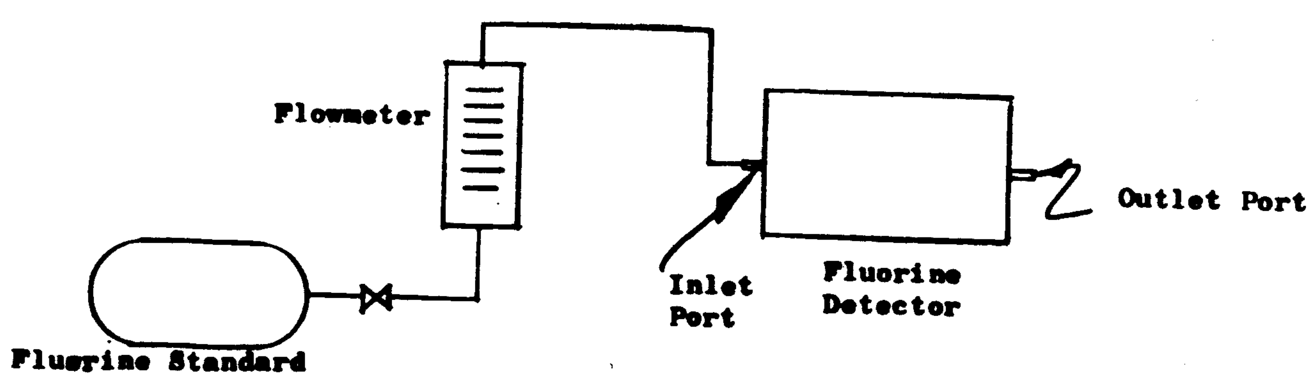


FIGURE 3. INSTRUMENT CALIBRATION

Figure 4. Calibration Sign-off Record

Calibration Record

GD/C Electronic Fluorine Detector, Model 00510

Procedure No. FLOX-00520   Instrument Serial No. S/N-1

Flowrate 220 cc/min   Fluorine Standard 32 ppm F_2

Recorder Output 11.5 div.   Instrument Factor 2.8 ppm F_2/div

Date 6/7/65   Signature D.A.Rau

Flowrate 208 cc/min   Fluorine Standard 1.1 ppm F_2

Recorder Output 13.3 div.   Instrument Factor 0.08 ppm F_2/div

Date 6/21/65   Signature D.A.Rau

Flowrate 215 cc/min   Fluorine Standard 6.9 ppm F_2

Recorder Output 49.2 div.   Instrument Factor 0.14 ppm F_2/div

Date 7/1/65   Signature D.A.Rau

Flowrate 225 cc/min   Fluorine Standard 7.2 ppm F_2

Recorder Output 15.0 div.   Instrument Factor 0.49 ppm F_2/div

Date 7/16/65   Signature D.A.Rau

Notes:

1. On 6/18/65, changed the 500 μamp recorder to a 10 μamp recorder, and also changed from buffered to unbuffered LiCl solution.
2. The results of the calibration on 7/16/65 appeared out of line, and instrument response was quite slow. The cells were therefor removed, cleaned and passivated, and recalibrated on 7/26/65. Cell cleaning and passivation was made a part of the calibration procedure for all further calibrations.

Figure 4. Calibration Sign-off Record

Calibration Record

GD/C Electronic Fluorine Detector, Model 00510

Procedure No. FLOX-00520 Instrument Serial No. S/N-1

Flowrate — cc/min Fluorine Standard 3.4 ppm F_2

Recorder Output 35.0 div. Instrument Factor 0.10 ppm F_2/div

Date 7/26/65 Signature D.A. Rau

Flowrate 200 cc/min Fluorine Standard 4.8 ppm F_2

Recorder Output 48.2 div. Instrument Factor 0.10 ppm F_2/div

Date 8/6/65 Signature D.A. Rau

Flowrate 200 cc/min Fluorine Standard 1.2 ppm F_2

Recorder Output 10.5 div. Instrument Factor 0.11 ppm F_2/div

Date 8/6/65 Signature D.A. Rau

Flowrate ______ cc/min Fluorine Standard ______ ppm F_2

Recorder Output ______ div. Instrument Factor ______ ppm F_2/div

Date ______ Signature ______

Figure 4. Calibration Sign-off Record

Calibration Record

GD/C Electronic Fluorine Detector, Model 00510

Procedure No. FLOX-00520   Instrument Serial No. S/N-2

Flowrate 211 cc/min   Fluorine Standard 32 ppm F_2

Recorder Output 11.0 div.   Instrument Factor 2.9 ppm F_2/div

Date 6/7/65   Signature D. A. Rau

Flowrate 200 cc/min   Fluorine Standard 6.9 ppm F_2

Recorder Output 15.3 div.   Instrument Factor 0.45 ppm F_2/div

Date 7/1/65   Signature D. A. Rau

Flowrate 225 cc/min   Fluorine Standard 7.2 ppm F_2

Recorder Output 11.2 div.   Instrument Factor 0.65 ppm F_2/div

Date 7/16/65   Signature D. A. Rau

Flowrate – cc/min   Fluorine Standard 3.4 ppm F_2

Recorder Output 28.0 div.   Instrument Factor 0.12 ppm F_2/div

Date 7/26/65   Signature D. A. Rau

Notes:

1. On 6/18/65, replaced the 500 μamp recorder with a 10 μamp recorder, and also changed from buffered to unbuffered LiCl solution. The instrument then would not respond to 1.1 ppm F_2. The cell was therefor removed, and cleaned and passivated.
2. The calibration results on 7/16/65 appeared out of line and instrument response was slow; the cells were therefor removed, cleaned and passivated, and recalibrated on 7/26/65. Cell cleaning and passivation was made a part of the procedure for all further calibrations.

Figure 4. Calibration Sign-off Record

Calibration Record

GD/C Electronic Fluorine Detector, Model 00510

Procedure No. FLOX-00520 Instrument Serial No. S/N-2

Flowrate 197 cc/min Fluorine Standard 4.8 ppm F_2

Recorder Output 37.3 div. Instrument Factor 0.13 ppm F_2/div

Date 8/6/65 Signature D.A. Rau

Flowrate 197 cc/min Fluorine Standard 1.2 ppm F_2

Recorder Output 10.3 div. Instrument Factor 0.12 ppm F_2/div

Date 8/6/65 Signature D.A. Rau

Flowrate ______ cc/min Fluorine Standard ______ ppm F_2

Recorder Output ______ div. Instrument Factor ______ ppm F_2/div

Date ______ Signature ______

Flowrate ______ cc/min Fluorine Standard ______ ppm F_2

Recorder Output ______ div. Instrument Factor ______ ppm F_2/div

Date ______ Signature ______

Figure 4. Calibration Sign-off Record

Calibration Record

GD/C Electronic Fluorine Detector, Model 00510

Procedure No. FLOX-00520 | Instrument Serial No. S/N-3

Flowrate 213 cc/min | Fluorine Standard 32 ppm F_2

Recorder Output 11.0 div. | Instrument Factor 2.9 ppm F_2/div

Date 6/7/65 | Signature D.A. Rau

Flowrate 223 cc/min | Fluorine Standard 1.1 ppm F_2

Recorder Output 21.1 div. | Instrument Factor 0.05 ppm F_2/div

Date 6/21/65 | Signature D.A. Rau

Flowrate 200 cc/min | Fluorine Standard 6.9 ppm F_2

Recorder Output 29 div. | Instrument Factor 0.24 ppm F_2/div

Date 7/1/65 | Signature D.A. Rau

Flowrate 220 cc/min | Fluorine Standard 7.2 ppm F_2

Recorder Output 2.0 div. | Instrument Factor 3.6 ppm F_2/div

Date 7/16/65 | Signature D.A. Rau

Notes:

1. On 6/18/65, changed the 500 μamp recorder to a 10 μamp recorder, and also changed from buffered to unbuffered LiCl solution.
2. The calibration results appeared out of line on 7/16/65 and the instrument response was slow; the cell was therefor removed, cleaned and passivated, and recalibration done on 7/26/65. Cell cleaning and passivation was made a part of the procedure for all further calibrations.

Figure 4. Calibration Sign-off Record

Calibration Record

GD/C Electronic Fluorine Detector, Model 00510

Procedure No. FLOX-00520 Instrument Serial No. S/N-3

Flowrate — cc/min Fluorine Standard 3.4 ppm F_2

Recorder Output 25.0 div. Instrument Factor 0.14 ppm F_2/div

Date 7/26/65 Signature D.A.Rau

Flowrate 215 cc/min Fluorine Standard 4.8 ppm F_2

Recorder Output 22.5 div. Instrument Factor 0.19 ppm F_2/div

Date 8/6/65 Signature D.A.Rau

Flowrate 215 cc/min Fluorine Standard 1.2 ppm F_2

Recorder Output 8.0 div. Instrument Factor 0.15 ppm F_2/div

Date 8/6/65 Signature D.A.Rau

Flowrate ________ cc/min Fluorine Standard ________ ppm F_2

Recorder Output ________ div. Instrument Factor ________ ppm F_2/div

Date ________ Signature ________

Figure 4. Calibration Sign-off Record

Calibration Record

GD/C Electronic Fluorine Detector, Model 00510

Procedure No. FLOX-00520 Instrument Serial No. S/N-4

Flowrate 213 cc/min Fluorine Standard 32 ppm F_2

Recorder Output 11.0 div. Instrument Factor 2.9 ppm F_2/div

Date 6/7/65 Signature D.A.Rau

Flowrate 207 cc/min Fluorine Standard 1.1 ppm F_2

Recorder Output 11.2 div. Instrument Factor 0.1 ppm F_2/div

Date 6/21/65 Signature D.A.Rau

Flowrate 202 cc/min Fluorine Standard 6.9 ppm F_2

Recorder Output 6.0 div. Instrument Factor 1.1 ppm F_2/div

Date 7/1/65 Signature D.A.Rau

Flowrate 206 cc/min Fluorine Standard 7.2 ppm F_2

Recorder Output 18.9 div. Instrument Factor 0.38 ppm F_2/div

Date 7/16/65 Signature D.A.Rau

Notes:

1. On 6/18/65, changed from original 500 μamp recorder to a 10 μamp recorder, and also changed from buffered to unbuffered LiCl solution.
2. Because of the questionable calibration results with the other instruments on 7/16/65, the cell of this instrument was also removed, cleaned and passivated, and re-calibrated on 7/26/65. Cell cleaning and passivation was incorporated into the procedure for all further calibrations.

Figure 4. Calibration Sign-off Record

Calibration Record

GD/C Electronic Fluorine Detector, Model 00510

Procedure No. FLOX-00520 Instrument Serial No. S/N-4

Flowrate — cc/min Fluorine Standard 3.4 ppm F_2

Recorder Output 13.6 div. Instrument Factor 0.25 ppm F_2/div

Date 7/26/65 Signature D.A.Rau

Flowrate 195 cc/min Fluorine Standard 4.8 ppm F_2

Recorder Output 22.3 div. Instrument Factor 0.21 ppm F_2/div

Date 8/6/65 Signature D.A.Rau

Flowrate 195 cc/min Fluorine Standard 1.2 ppm F_2

Recorder Output 5.5 div. Instrument Factor 0.22 ppm F_2/div

Date 8/6/65 Signature D.A.Rau

Flowrate ______ cc/min Fluorine Standard ______ ppm F_2

Recorder Output ______ div. Instrument Factor ______ ppm F_2/div

Date ______ Signature ______

Figure 4. Calibration Sign-off Record

Calibration Record

GD/C Electronic Fluorine Detector, Model 00510

Procedure No. FLOX-00520

Instrument Serial No. S/N-5

Flowrate 213 cc/min

Fluorine Standard 32 ppm F_2

Recorder Output 10.8 div.

Instrument Factor 3.0 ppm F_2/div

Date 6/7/65

Signature D. A. Rau

Flowrate 211 cc/min

Fluorine Standard 1.1 ppm F_2

Recorder Output 16.0 div.

Instrument Factor 0.07 ppm F_2/div

Date 6/21/65

Signature D. A. Rau

Flowrate 147 cc/min

Fluorine Standard 6.9 ppm F_2

Recorder Output — div.

Instrument Factor — ppm F_2/div

Date 7/1/65

Signature D. A. Rau

Flowrate ____ cc/min

Fluorine Standard ____ ppm F_2

Recorder Output ____ div.

Instrument Factor ____ ppm F_2/div

Date ____

Signature ____

Notes:

1. On 6/18/65, changed from 500 μamp recorder to a 10 μamp recorder, and also changed from buffered to unbuffered LiCl solution.

2. The instrument did not respond to fluorine during the calibration on 7/1/65. The cell was removed, cleaned and passivated, after which a positive response to fluorine was observed. The instrument was returned to field use without calibration.

3. Prior to calibration on 7/16/65, the instrument was dropped, and the cell and the recorder broken. The instrument was not used again in the program.

Figure 4. Calibration Sign-off Record

Calibration Record

GD/C Electronic Fluorine Detector, Model 00510

Procedure No. FLOX-00520

Instrument Serial No. S/N-6

Flowrate 218 cc/min

Fluorine Standard 32 ppm F_2

Recorder Output 12.0 div.

Instrument Factor 2.7 ppm F_2/div

Date 6/7/65

Signature D.A. Rau

Flowrate 223 cc/min

Fluorine Standard 1.1 ppm F_2

Recorder Output 24.3 div.

Instrument Factor 0.05 ppm F_2/div

Date 6/21/65

Signature D.A. Rau

Flowrate 204 cc/min

Fluorine Standard 6.9 ppm F_2

Recorder Output 47.0 div.

Instrument Factor 0.15 ppm F_2/div

Date 7/1/65

Signature D.A. Rau

Flowrate 222 cc/min

Fluorine Standard ~~0.41~~ 7.2 ppm F_2

Recorder Output 17.8 div.

Instrument Factor 0.41 ppm F_2/div

Date 7/16/65

Signature D.A. Rau

Notes:

1. On 6/18/65, changed from 500 μamp recorder to a 10 μamp recorder, and also changed from buffered to unbuffered LiCl solution.
2. The calibration results of 7/16/65 appeared to be out of line, and the instrument response was slow; the cell was therefor removed, cleaned and passivated, and recalibration performed on 7/26/65. Cell cleaning and passivation was incorporated in the procedure for all further calibrations.

Figure 4. Calibration Sign-off Record

Calibration Record

GD/C Electronic Fluorine Detector, Model 00510

Procedure No. FLOX-00520 Instrument Serial No. S/N-6

Flowrate — cc/min Fluorine Standard 3.4 ppm F_2

Recorder Output 32.5 div. Instrument Factor 0.10 ppm F_2/div

Date 7/26/65 Signature D.A. Rau

Flowrate 225 cc/min Fluorine Standard 4.8 ppm F_2

Recorder Output 44.6 div. Instrument Factor 0.11 ppm F_2/div

Date 8/6/65 Signature D.A. Rau

Flowrate 225 cc/min Fluorine Standard 1.2 ppm F_2

Recorder Output 17.8 div. Instrument Factor 0.07 ppm F_2/div

Date 8/6/65 Signature D.A. Rau

Flowrate______ cc/min Fluorine Standard______ ppm F_2

Recorder Output______ div. Instrument Factor______ ppm F_2/div

Date______ Signature______

APPENDIX II

CALIBRATION PROCEDURE 00519

GD/C CHEMICAL FLUORINE AND FLUORIDE ANALYZER

MODEL 00509

GENERAL DYNAMICS/CONVAIR

CALIBRATION PROCEDURE

GD/C CHEMICAL FLUORINE

AND FLUORIDE ANALYZER

MODEL 00509

FLOX-00519

FLOX

PREPARED BY D. A. Ross

APPROVED BY W. M. Gross

CHECKED BY R. L. Barrows

APPROVED BY G. R. Stone

APPROVED BY J. R. Thayer

FLOX
RELEASED R.D.V.
DATE 5/16/65
CHG. LETTER —

CALIBRATION PROCEDURE
GD/C CHEMICAL FLUORINE AND FLUORIDE ANALYZER
MODEL 00509

I. SCOPE

This document describes the calibration procedure and requirements for the GD/C Chemical Fluorine and Fluoride Analyzer, Model 00509. This document is written for use in the Atmospheric Diffusion Control of FLOX and HF at Sycamore test program (NAS-3245). Applicability of this procedure to other test programs shall be determined by the cognizant program office.

The chemical analysis procedure used by this instrument is considered to be as accurate as other methods of analysis for fluorine and fluoride at very low concentrations. Accordingly, calibration of the instrument is limited to calibration of the pump flow rate.

II. INSTRUMENTATION REQUIREMENTS

A. Flowmeter

A flowmeter calibrated for the range of 100 to 500 cubic centimeters per minute is required.

B. Timer

A calibrated timer which indicates seconds elapsed time from start is required. The timer shall have a minimum capacity of 300 seconds.

III. PROCEDURE

Fill the absorption cylinder with 100 milliliters of 1% potassium iodide solution. Verify that the inlet tube is open and connected to the pump, and that the tube from the pump to the absorption cylinder and the outlet tube from the absorption cylinder are connected and open. Connect the outlet tube to the flowmeter inlet. Start the pump and allow it to run for five minutes. Read and record the flowrate reading on the flowmeter.

IV. FREQUENCY AND SIGN-OFF REQUIREMENTS

A. Frequency

Each instrument shall be calibrated prior to initial use. Thereafter, each instrument shall be calibrated after each three test runs or 15 hours running time, whichever occurs first.

IV. FREQUENCY AND SIGN-OFF REQUIREMENTS (Continued)

B. Sign-off

A calibration record shall be maintained for each instrument (Figure 1.). The record shall include the calibration procedure number, the instrument model and serial numbers, the calibration data obtained, date of calibration, and signature of the person performing the calibration.

CALIBRATION RECORD
GD/C CHEMICAL FLUORINE AND FLUORIDE ANALYZER
MODEL 00509

Procedure No. FLOX-00519 Instrument Serial No. S/N-1

Date 6/2/65 Flowrate 211 cc/min
Signature D.A. Rau

Date 6/14/65 Flowrate 205 cc/min
Signature D.A. Rau

Date 7/1/65 Flowrate 225 cc/min
Signature D.A. Rau

Date 7/16/65 Flowrate 222 cc/min
Signature D.A. Rau

Date 8/6/65 Flowrate 193 cc/min
Signature DA. Rau

Date 9/17/65 Flowrate 196 cc/min
Signature D.A. Rau

Notes:
1. On 6/9/65, a single source of F_2/Air was sampled with all four Model 00509 instruments, and the average of the four analyses was 31.9 ppm F_2. S/N-1 analysis was 32.4 ppm.

CALIBRATION RECORD
GD/C CHEMICAL FLUORINE AND FLUORIDE ANALYZER
MODEL 00509

Procedure No. FLOX-00519 Instrument Serial No. S/N-2

Date 6/2/65 Flowrate 227 cc/min

Signature D.A. Rau

Date 6/14/65 Flowrate 223 cc/min

Signature D.A. Rau

Date 7/1/65 Flowrate 212 cc/min

Signature D.A. Rau

Date 7/16/65 Flowrate 226 cc/min

Signature D.A. Rau

Date 8/6/65 Flowrate 209 cc/min

Signature D.A. Rau

Date 9/17/65 Flowrate 200 cc/min

Signature D.A. Rau

Notes:

1. On 6/9/65, a single source of F_2/Air was analyzed with all four Model 00509 instruments and gave an average of 31.9 ppm F_2. The analysis with S/N-2 was 31.2 ppm.

CALIBRATION RECORD

GD/C CHEMICAL FLUORINE AND FLUORIDE ANALYZER

MODEL 00509

Procedure No. FLOX-00519 Instrument Serial No. S/N-3

Date 6/2/65 Flowrate 227 cc/min

Signature D.A. Rau

Date 6/14/65 Flowrate 227 cc/min

Signature D.A. Rau

Date 7/1/65 Flowrate 227 cc/min

Signature D.A. Rau

Date 7/16/65 Flowrate 231 cc/min

Signature D.A. Rau

Date 8/6/65 Flowrate 216 cc/min

Signature D.A. Rau

Date 9/17/65 Flowrate 209 cc/min

Signature D.A. Rau

Notes:

1. On 6/9/65, a single source of F_2/Air was analyzed with all four Model 00509 instruments and gave an average of 31.9 ppm F_2. The analysis with S/N-3 was 35.8 ppm.

CALIBRATION RECORD
GD/C CHEMICAL FLUORINE AND FLUORIDE ANALYZER
MODEL 00509

Procedure No. FLOX-00519 Instrument Serial No. S/N-4

Date 6/2/65 Flowrate 219 cc/min
Signature D.A.Rau

Date 6/14/65 Flowrate 224 cc/min
Signature D.A.Rau

Date 7/1/65 Flowrate 227 cc/min
Signature D.A.Rau

Date 7/16/65 Flowrate 228 cc/min
Signature D.A.Rau

Date 8/6/65 Flowrate 222 cc/min
Signature D.A.Rau

Date 9/17/65 Flowrate 217 cc/min
Signature D.A.Rau

Notes:

1. On 6/9/65, a single source of F_2/Air was simultaneously analyzed with all four Model 00509 instruments; the analyses average was 31.9 ppm F_2. The analysis with S/N-4 gave 28.3 ppm.

APPENDIX III

CALIBRATION PROCEDURE 00518

TRACER LAB FLUORINE MONITOR

MODEL FM-2

TRACER LAB FLUORINE MONITOR

MODEL FM-2

CALIBRATION PROCEDURE

FLOX-00518

FLOX

PREPARED BY D. A. Rau CHECKED BY Hugh L. Tinsley

APPROVED BY W. M. Gross APPROVED BY RJB E. R. Kimmy

APPROVED BY J. R. Thayer

FLOX
RELEASED HLT.
DATE 9/16/65
CHG. LETTER –

I. SCOPE

This document describes the calibration requirements and procedure for the Tracer Lab Fluorine Monitor, Model FM-2. This document is written for use in the Atmospheric Diffusion Control of FLOX and HF at Sycamore test program (NAS-3245). Applicability of this procedure to other test programs shall be determined by the cognizant program office.

II. MATERIALS AND INSTRUMENTATION REQUIREMENTS

A. Fluorine Standard

A cylinder of air containing 5 to 50 ppm by volume of fluorine is required. The fluorine concentration is determined by absorbing a measured volume of the fluorine standard in 1% potassium iodide solution. The potassium iodide solution is then analyzed for fluoride by the colorimetric analysis given in FLOX Procedure 00521, Paragraph III. D.3.

B. Flowmeter

A flowmeter calibrated for the range of 50 to 200 cubic centimeters per minute is required to calibrate the instrument pump flow rate. A second flowmeter calibrated for the range of 100 to 500 cubic centimeters per minute is required for calibration of the fluorine standard.

C. Timer

A calibrated timer which indicates seconds elapsed time from start is required. The timer shall have a minimum capacity of 300 seconds.

D. Absorption Cylinder

The absorption cylinder is a 250 milliliter polypropylene graduated cylinder, equipped with a 2-hole rubber stopper cap. The inlet and outlet tubes of the cylinder are polytetrafluoroethylene tubing.

III. PROCEDURE

A. Pump Flowrate

Connect the 200 cc/min flowmeter outlet to the input port of the instrument. Turn the Main Function switch on the instrument to the "Zero" position. Allow the instrument to run for 5 minutes, then regulate the Flow Control valve to give a measured flowrate of 100 cubic centimeters/minute.

III. PROCEDURE (Continued)

B. Fluorine Standard Calibration

Connect the fluorine standard to the inlet of the 500 cc/min flowmeter. Connect the flowmeter outlet to the inlet tube of the absorption cylinder, but do not place the tube in the absorption cylinder (Figure 1.). Open the fluorine standard cylinder valve and adjust the flowrate to 250 cubic centimeters per minute. Fill the absorption cylinder with 100 milliliters of 1% potassium iodide solution. Place the absorption cylinder inlet tube into the absorption cylinder, and immediately start the timer (Figure 2.). Record the initial flowmeter reading, and at one minute intervals. After 5 minutes turn off the fluorine standard cylinder valve, and disconnect the apparatus. Calculate the volume in cubic centimeters of fluorine standard passed through the potassium iodide solution.

Determine the weight of fluoride absorbed in the potassium iodide solution by the colorimetric analysis for fluoride given in Procedure 00521, Paragraph III.D.3. Finally, calculate the fluorine concentration of the fluorine standard in parts per million by volume. The calculation is:

$$\text{ppm } F_2 \text{ by volume} = (\text{milligrams fluoride absorbed} \times 5.9 \times 10^5) \div (\text{cubic centimeters of fluorine standard})$$

C. Instrument Calibration

Turn the Main Function switch on the instrument to the "Zero" position, and set the recorder pen to coincide with the chart zero line. Connect the fluorine standard to the inlet of the 200 cc/min flowmeter and connect the flowmeter outlet to the inlet port of the instrument (Figure 3.). Set the R.H. Control to 1000 and turn the Main Function switch to the 100K position. Set the Time Constant switch to 10 seconds. Open the fluorine standard cylinder valve until the flowmeter reading equals 100 cubic centimeters per minute. Continue the fluorine standard flow until the recorder indicates a steady reading. Turn the Main Function switch to the 30K position, and repeat the reading. Finally, turn the Main Function switch to the 10K position and repeat the reading, provided the recorder pen remains on scale. Turn off the fluorine standard and the instrument, and disconnect the apparatus. From the fluorine concentration of the fluorine standard and the recorder output, calculate the instrument sensitivity in units of ppm fluorine by volume per recorder scale division, for each of the three counting rate ranges.

III. PROCEDURE (Continued)

D. Fluorine Standard Recalibration

If two or more instruments are to be calibrated from the same fluorine standard, it is necessary to determine the fluorine concentration of the fluorine standard only before and after the entire instrument calibration run. However, do not use more than 25% by volume of the fluorine standard between calibrations; this is to minimize effects of fluorine release from the fluorine standard cylinder walls.

IV. Frequency and Sign-off Requirements

A. Frequency

Each instrument shall be calibrated prior to initial use. Thereafter, each instrument shall be calibrated after each three test runs or 15 hours running time, whichever occurs first.

B. Sign-off

A calibration record shall be maintained for each instrument (Figure 4.). The record shall include the calibration procedure number, instrument model and serial numbers, calibration data obtained, date of calibration, and signature of the person performing the calibration.

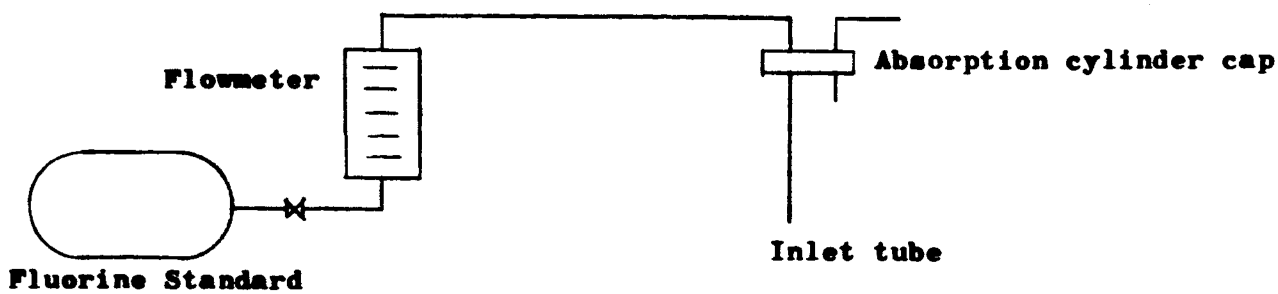


FIGURE 1. FLUORINE STANDARD CALIBRATION, FLOWRATE ADJUSTMENT

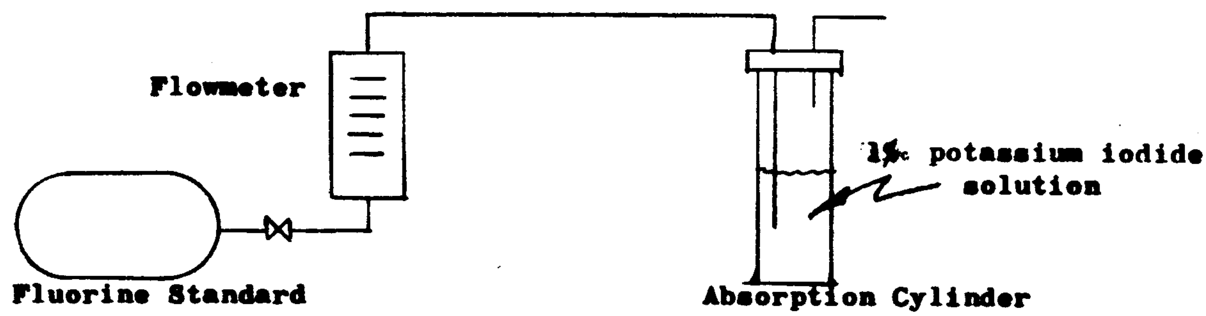


FIGURE 2. FLUORINE STANDARD CALIBRATION, FLUORINE ABSORPTION

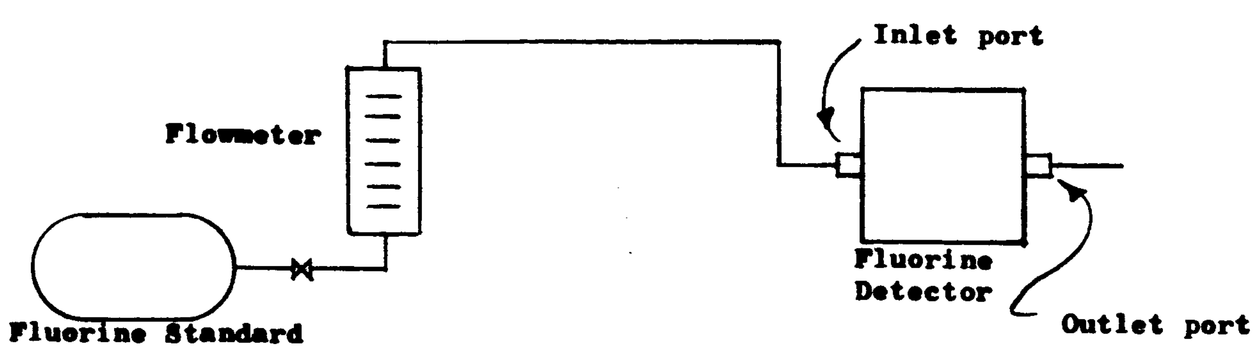


FIGURE 3. INSTRUMENT CALIBRATION

FIGURE 4. CALIBRATION SIGN-OFF RECORD

Calibration Record
Tracer Lab Fluorine Monitor, Model FM-2

Procedure No. FLOX-00518 Instrument Serial No. S/N-1

Flowrate 100 cc/min Fluorine Standard 12.7 ppm F_2

Recorder Output		Instrument Factor
100K range 6.3 div.		2.0 ppm F_2/div.
30K range 16.7 div.		0.76 ppm F_2/div.
10K range — div.	(off-scale)	— ppm F_2/div.

Date 6/10/65 Signature D.A. Rau

Flowrate 100 cc/min Fluorine Standard 6.9 ppm F_2

Recorder Output		Instrument Factor
100K range — div.	(no reading)	— ppm F_2/div.
30K range 3.8 div.		1.8 ppm F_2/div.
10K range 9.5		0.73 ppm F_2/div.

Date 7/1/65 Signature D.A. Rau

Notes:
1. On 6/10/65, the instrument was zeroed on dry air for calibration. The instrument gave an output of 1.0 div. on the 10K scale with 138 ppm HF.
2. On 7/1/65, the instrument was zeroed on ambient air at Sycamore Site 2 for calibration. The flowrate before adjustment was 62 cc/min.

FIGURE 4. CALIBRATION SIGN-OFF RECORD

Calibration Record
Tracer Lab Fluorine Monitor, Model FM-2

Procedure No. FLOX-00518 — Instrument Serial No. S/N-1

Flowrate 16 cc/min — Fluorine Standard 7.2 ppm F_2

Recorder Output			Instrument Factor
100K range	— div.	(no reading)	— ppm F_2/div.
30K range	1.1 div.		6.6 ppm F_2/div.
10K range	3.5 div.		2.1 ppm F_2/div.

Date 7/16/65 — Signature D.A. Rau

Flowrate 31 cc/min — Fluorine Standard 930 ppm F_2

Recorder Output			Instrument Factor
100K range	— div.	(no reading)	— ppm F_2/div.
30K range	1.0 div.		— ppm F_2/div.
10K range	2.0		— ppm F_2/div.

Date 8/6/65 — Signature D.A. Rau

Notes:

3. On 7/16/65, the instrument was zeroed on dry air for calibration, and the flowrate before adjustment was also 16 cc/min. The malfunction was eventually traced to a cracked foil seal on the counting chamber.
4. Because of the essentially zero output on 8/6/65, the cells were removed and returned to Tracerlab for examination. New cells were received and installed, and the instruments recalibrated on 9/1/65. At this time the cause of the malfunction in the flow system on this instrument was discovered, but repair could not be made in time to complete the calibration before the end of the program.

FIGURE 4. CALIBRATION SIGN-OFF RECORD

Calibration Record
Tracer Lab Fluorine Monitor, Model FM-2

Procedure No. FLOX-00518

Instrument Serial No. S/N-2

Flowrate 100 cc/min

Fluorine Standard 12.7 ppm F_2

Recorder Output		Instrument Factor
100K range	12.0 div.	1.1 ppm F_2/div.
30K range	46.7 div.	0.27 ppm F_2/div.
10K range	– div. (off-scale)	– ppm F_2/div.

Date 6/10/65

Signature D.A. Rau

Flowrate 100 cc/min

Fluorine Standard 6.9 ppm F_2

Recorder Output		Instrument Factor
100K range	– div. (no reading)	– ppm F_2/div.
30K range	4.7 div.	1.5 ppm F_2/div.
10K range	11.4	0.61 ppm F_2/div.

Date 7/1/65

Signature D.A. Rau

Notes:

1. On 6/10/65, the instrument was zeroed on dry air for calibration. The instrument gave an output of 1.0 div. on the 10K scale with 138 ppm HF.
2. On 7/1/65, the instrument was zeroed on ambient air at Sycamore Site 2 for calibration. The flowrate before adjustment was 78 cc/min.

FIGURE 4. CALIBRATION SIGN-OFF RECORD

Calibration Record
Tracer Lab Fluorine Monitor, Model FM-2

Procedure No. FLOX-00518

Instrument Serial No. S/N-2

Flowrate 100 cc/min

Fluorine Standard 7.2 ppm F_2

Recorder Output

		Instrument Factor
100K range	– div. (no reading)	– ppm F_2/div.
30K range	4.9 div.	1.5 ppm F_2/div.
10K range	12.2 div.	0.59 ppm F_2/div.

Date 7/16/65

Signature D.A. Rau

Flowrate 100 cc/min

Fluorine Standard 430 ppm F_2

Recorder Output

		Instrument Factor
100K range	– div. (no reading)	– ppm F_2/div.
30K range	2.5 div.	– ppm F_2/div.
10K range	6.5	– ppm F_2/div.

Date 8/6/65

Signature D.A. Rau

Notes:

3. On 7/16/65 the instrument was zeroed on dry air for instrument calibration, and the flowrate before adjustment was 100 cc/min.

4. Because of the essentially zero output on 8/6/65, the clathrate cell was removed and returned to Tracerlab for examination. A new cell was received and installed, and the instrument recalibrated on 9/1/65.

FIGURE 4. CALIBRATION SIGN-OFF RECORD

Calibration Record
Tracer Lab Fluorine Monitor, Model FM-2

Procedure No. FLOX-00518

Instrument Serial No. S/N 2

Flowrate 100 cc/min

Fluorine Standard 54 ppm F_2

Recorder Output

100K range 4.0 div.
30K range 13.2 div.
10K range – div. (off-scale)

Instrument Factor

13.5 ppm F_2/div.
4.1 ppm F_2/div.
– ppm F_2/div.

Date 9/1/65

Signature D.A. Rau

Flowrate 100 cc/min

Fluorine Standard 31 ppm F_2

Recorder Output

100K range 2.2 div.
30K range 7.0 div.
10K range 27.6

Instrument Factor

14.1 ppm F_2/div.
4.6 ppm F_2/div.
1.2 ppm F_2/div.

Date 9/1/65

Signature D.A. Rau

Notes:
5. The instrument was zeroed on dry air for both calibrations on 9/1/65.

FIGURE 4. CALIBRATION SIGN-OFF RECORD

Calibration Record
Tracer Lab Fluorine Monitor, Model FM-2

Procedure No. FLOX-00518 Instrument Serial No. S/N-3

Flowrate 100 cc/min Fluorine Standard 12.7 ppm F_2

Recorder Output		Instrument Factor
100K range	14.8 div.	0.86 ppm F_2/div.
30K range	35.0 div.	0.36 ppm F_2/div.
10K range	— div. (off-scale)	— ppm F_2/div.

Date 6/10/65 Signature D.A. Rau

Flowrate 100 cc/min Fluorine Standard 6.9 ppm F_2

Recorder Output		Instrument Factor
100K range	— div. (no reading)	— ppm F_2/div.
30K range	1.9 div.	3.6 ppm F_2/div.
10K range	4.7	1.4 ppm F_2/div.

Date 7/1/65 Signature D.A. Rau

Notes:

1. On 6/10/65, the instrument was zeroed on dry air for the calibration. The instrument also gave an output of 3.5 div. on the 10K scale with 138 ppm HF.
2. On 7/1/65, the instrument was zeroed on ambient air at Sycamore Site 2 for calibration. The flowrate before adjustment was 97 cc/min.

FIGURE 4. CALIBRATION SIGN-OFF RECORD

Calibration Record
Tracer Lab Fluorine Monitor, Model FM-2

Procedure No. FLOX-00518 Instrument Serial No. S/N 3

Flowrate 100 cc/min Fluorine Standard 7.2 ppm F_2

Recorder Output			Instrument Factor
100K range	– div.	(no reading)	– ppm F_2/div.
30K range	2.1 div.		3.4 ppm F_2/div.
10K range	5.0 div.		1.4 ppm F_2/div.

Date 7/16/65 Signature D.A.Rau

Flowrate 100 cc/min Fluorine Standard 930 ppm F_2

Recorder Output			Instrument Factor
100K range	– div.	(no reading)	– ppm F_2/div.
30K range	2.2 div.		– ppm F_2/div.
10K range	2.0		– ppm F_2/div.

Date 8/6/65 Signature D.A.Rau

Notes:

3. The instrument was zeroed on dry air for calibration on 7/16/65. The flowrate before adjustment was 120 cc/min.

4. Because of the essentially zero response on 8/6/65, the clathrate cell was removed and returned to Tracerlab for examination. A new cell was received and installed, and the instrument recalibrated on 9/1/65.

FIGURE 4. CALIBRATION SIGN-OFF RECORD

Calibration Record
Tracer Lab Fluorine Monitor, Model FM-2

Procedure No. FLOX-00518

Instrument Serial No. S/N-3

Flowrate 100 cc/min

Fluorine Standard 54 ppm F_2

Recorder Output		Instrument Factor
100K range	2.5 div.	19.3 ppm F_2/div.
30K range	9.0 div.	6.0 ppm F_2/div.
10K range	37.5 div.	1.4 ppm F_2/div.

Date 9/1/65

Signature D.A.Rau

Flowrate 100 cc/min

Fluorine Standard 31 ppm F_2

Recorder Output		Instrument Factor
100K range	1.5 div.	21.3 ppm F_2/div.
30K range	5.2 div.	6.2 ppm F_2/div.
10K range	19.6	1.6 ppm F_2/div.

Date 9/1/65

Signature D.A.Rau

Notes:

5. The instrument was zeroed on dry air for both calibrations on 9/1/65.

APPENDIX IV

CALIBRATION PROCEDURE 00517

DAVIS INSTRUMENTS HYDROGEN FLUORIDE DETECTOR

MODEL 11-7010-RP-SPECIAL

GENERAL DYNAMICS/CONVAIR

CALIBRATION PROCEDURE

DAVIS INSTRUMENTS HYDROGEN FLUORIDE

DETECTOR

MODEL 11-7010-RP-SPECIAL

FLOX-00517

FLOX

PREPARED BY D. A. Ra

APPROVED BY W. M. Gross

CHECKED BY R. L. Barrows

APPROVED BY G. K. Ston

APPROVED BY J. R. Thayer

CHG. LETTER
DATE
RELEASED
FLOX

FLOX
RELEASED KRF
DATE 9/14/65
CHG. LETTER —

Calibration Procedure
Davis Instruments Hydrogen Fluoride Detector
Model 11-7010-RP-Special

FLOX-00517

I. SCOPE

This document describes the calibration requirements and procedure for the Davis Instruments Hydrogen Fluoride Detector, Model 11-7010-RP-Special. This document is written for use in the Atmospheric Diffusion Control of FLOX and HF at Sycamore test program (NAS-3245). Applicability of this procedure to other test programs shall be determined by the cognizant program office.

II. MATERIALS AND INSTRUMENTATION REQUIREMENTS

A. Hydrogen Fluoride Standard

A cylinder of air containing 25 to 250 ppm by volume of hydrogen fluoride is required. The hydrogen fluoride concentration is determined by absorbing a measured volume of the hydrogen fluoride standard in 1% potassium iodide solution. The potassium iodide solution is then analysed for fluoride by the colorimetric analysis given in FLOX Procedure 00521, Paragraph III D. 2.

B. Flowmeter

A flowmeter calibrated for the range of 100 to 500 cubic centimeters per minute is required.

C. Timer

A calibrated timer which indicates seconds elapsed time from start is required. The timer shall have a minimum capacity of 300 seconds.

D. Absorption Cylinder

The absorption cylinder is a 250 milliliter polypropylene graduated cylinder, equipped with a 2-hole rubber stopper cap. The inlet and outlet tubes to the cylinder are polytetrafluoroethylene tubing.

III. PROCEDURE

A. Hydrogen Fluoride Standard Calibration

Connect the hydrogen fluoride standard to the inlet of the flowmeter.

III. **PROCEDURE** (Continued)

Connect the flowmeter outlet to the inlet tube of the absorption cylinder, but do not place the tube in the absorption cylinder, (Figure 1.). Open the hydrogen fluoride standard cylinder valve and adjust the flowrate to 250 cubic centimeters per minute. Fill the aboarption cylinder with 100 milliliters of 1% potassium iodide solution. Place the absorption cylinder inlet tube into the absorption cylinder, and immediately start the timer (Figure 2.). Record the initial flowmeter reading, and at one minute intervals. After five minutes turn off the hydrogen fluoride standard and disconnect the apparatus. Calculate the volume in cubic centimeters of hydrogen fluoride standard passed through the potassium iodide solution.

Determine the weight of fluoride absorbed in the potassium iodide solution by the colorimetric analysis for fluoride given in FLOX Procedure 00521, Paragraph III.D.2. Finally calculate the hydrogen fluoride concentration of the hydrogen fluoride standard in parts per million by volume. The calculation is:

ppm HF by volume =
(milligrams fluoride absorbed x $1.18x10^6$) ÷
(cubic centimeters of hydrogen fluoride standard)

B. Instrument Calibration

Turn the instrument power switch to the "ON" position. Turn the Flow Adjust needle valve to obtain a reading of 2.0 cubic feet per hour on the Sample Flow Meter. Adjust the Sample Water Ratio Adjust needle valve to obtain a reading of 4 cubic centimeters per minute on the Water Flow Meter. Readjust the Flow Adjust needle valve to obtain a reading of 2.0 cubic feet per hour on the Sample Flow Meter. Depress the Water Check pushbutton and zero the recorder and meter. Connect the hydrogen fluoride standard to the Sample Inlet on the instrument. Open the cylinder valve until the Sample Flow Meter reading equals 2.0 cubic feet per hour. Continue the hydrogen fluoride standard flow until the recorder indicates a steady reading. Turn off the hydrogen fluoride standard and the instrument, and disconnect the apparatus. From the hydrogen fluoride concentration in the standard and the recorder output, calculate the instrument sensitivity in units of parts per million hydrogen fluoride by volume per recorder scale division.

C. Hydrogen Fluoride Standard Recalibration

If two or more instruments are to be calibrated from the same hydrogen fluoride standard, it is necessary to determine the hydrogen fluoride concentration of the standard only before and after the entire instrument calibration run. However, do not use more than 25% by volume of the hydrogen fluoride standard between calibration: this is to minimize effects of hydrogen fluoride release from the cylinder walls.

IV. FREQUENCY AND SIGN-OFF REQUIREMENTS

A. Frequency

Each instrument shall be calibrated prior to initial use. Thereafter, each instrument shall be calibrated after each three test runs, or 15 hours running time, whichever occurs first.

B. Sign-Off

A calibration record shall be maintained for each instrument (Figure 3.). The record shall include the calibration procedure number, instrument model and serial numbers, calibration data obtained, date of calibration, and signature of the person performing the calibration.

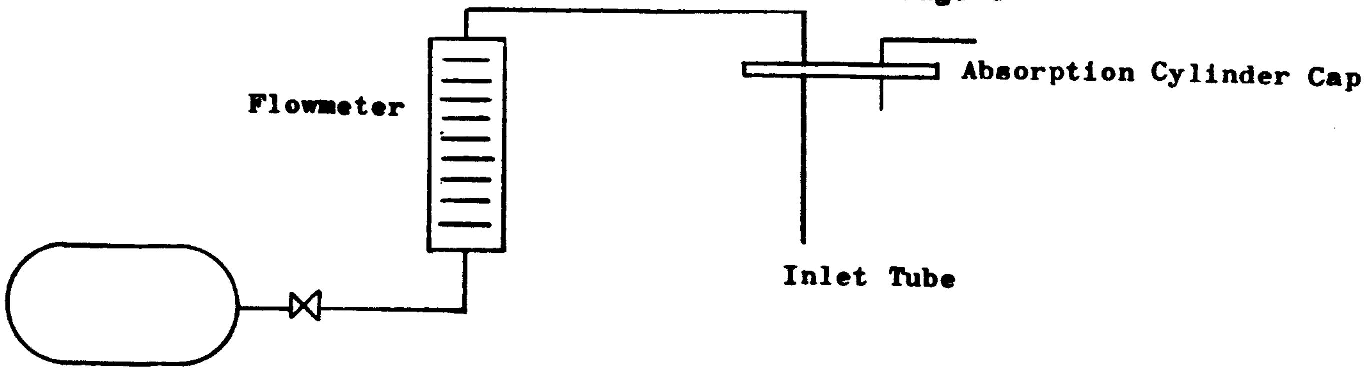


Figure 1. Hydrogen Fluoride Standard calibration, flowrate adjustment

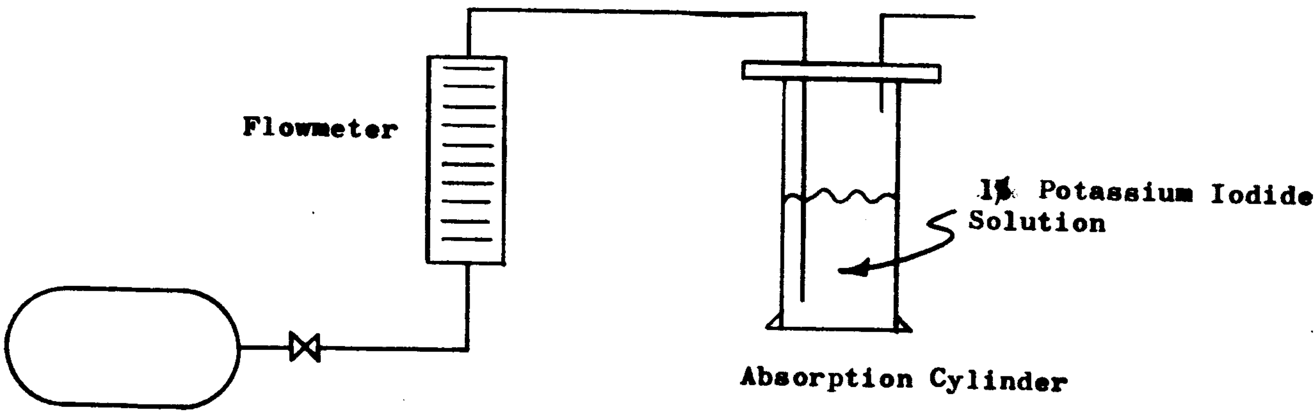


Figure 2. Hydrogen Fluoride standard calibration, hydrogen fluoride absorption.

Figure 3. Calibration sign-off record

Calibration Record
Davis Instruments Hydrogen Fluoride Detector
Model 11-7010-RP-Special

Procedure No. FLOX-00517 Instrument Serial No. 65-159

Sample Flowrate 2.0 cfh Water Flowrate 4.0 cc/min

Hydrogen Fluoride Standard 90 ppm HF

Recorder Output 21.6 div. Instrument Factor 4.1 ppm HF/div

Date 8/30/65 Signature D.A. Rau

Sample Flowrate ________ Water Flowrate ________

Hydrogen Fluoride Standard ________ ppm HF

Recorder Output ________ div. Instrument Factor ________ ppm HF/div

Date ________ Signature ________

Sample Flowrate ________ Water Flowrate ________

Hydrogen Fluoride Standard ________ ppm HF

Recorder Output ________ div. Instrument Factor ________ ppm HF/div

Date ________ Signature ________

Notes:

4. The original aluminum pumps were replaced with stainless steel pumps prior to calibration on 8/6/65.

Figure 3. Calibration sign-off record

Calibration Record
Davis Instruments Hydrogen Fluoride Detector
Model 11-7010-RP-Special

Procedure No. FLOX-00517 Instrument Serial No. 65-159

Sample Flowrate 2.0 cfh Water Flowrate 4.0 cc/min.
Hydrogen Fluoride Standard 138 ppm HF
Recorder Output 29 div. Instrument Factor 4.8 ppm HF/div
Date 6/9/65 Signature D.A. Rau

Sample Flowrate 2.0 cfh Water Flowrate 4.0 cc/min
Hydrogen Fluoride Standard 53 ppm HF
Recorder Output 21.0 div. Instrument Factor 2.5 ppm HF/div
Date 8/6/65 Signature D.A. Rau

Sample Flowrate 4.0 cfh Water Flowrate 4.0 cc/min
Hydrogen Fluoride Standard 147 ppm HF
Recorder Output 39.2 div. Instrument Factor 3.7 ppm HF/div
Date 8/30/65 Signature D.A. Rau

Notes:

1. On 6/10/65, with standard sample and water flowrates, 24 ppm F_2 gave an output of 9.5 divisions for a sensitivity of 2.5 ppm F_2/div.

2. On 7/1/65 the recorder resistor was removed. It was not possible to perform an instrument calibration on this date, due to insufficient pump flowrate.

3. On 7/16/65 the pump malfunction was still uncorrected.

Figure 3. Calibration sign-off record

Calibration Record
Davis Instruments Hydrogen Fluoride Detector
Model 11-7010-RP-Special

Procedure No. FLOX-00517 Instrument Serial No. 65-160

Sample Flowrate 2.0 cfh Water Flowrate 4.0 cc/min.

Hydrogen Fluoride Standard 138 ppm HF

Recorder Output 29 div. Instrument Factor 4.8 ppm HF/div

Date 6/9/65 Signature D.A. Rau

Sample Flowrate 2.0 cfh Water Flowrate 4.0 cc/min.

Hydrogen Fluoride Standard 24.5 ppm HF

Recorder Output 11.2 div. Instrument Factor 2.2 ppm HF/div

Date 7/1/65 Signature D.A. Rau

Sample Flowrate 2.0 cfh Water Flowrate 4.0 cc/min

Hydrogen Fluoride Standard 25.4 ppm HF

Recorder Output 14.3 div. Instrument Factor 1.8 ppm HF/div

Date 7/16/65 Signature D.A. Rau

Notes:

1. On 6/10/65, with standard sample and water flowrates, 24 ppm F_2 gave 9.5 divisions recorder output, for a sensitivity of 2.5 ppm F_2/div.

2. On 7/1/65, the recorder resistor was removed prior to instrument calibration.

Figure 3. Calibration sign-off record

Calibration Record
Davis Instruments Hydrogen Fluoride Detector
Model 11-7010-RP-Special

Procedure No. FLOX-00517 Instrument Serial No. 65-160

Sample Flowrate 2.0 cfh Water Flowrate 4.0 cc/min

Hydrogen Fluoride Standard 53 ppm HF

Recorder Output 18.2 div. Instrument Factor 2.9 ppm HF/div

Date 8/6/65 Signature D.A. Rau

Sample Flowrate 2.0 cfh Water Flowrate 4.0 cc/min

Hydrogen Fluoride Standard 147 ppm HF

Recorder Output 41.8 div. Instrument Factor 3.5 ppm HF/div

Date 8/30/65 Signature D.A. Rau

Sample Flowrate 2.0 cfh Water Flowrate 4.0 cc/min

Hydrogen Fluoride Standard 90 ppm HF

Recorder Output 23.0 div. Instrument Factor 3.9 ppm HF/div

Date 8/30/65 Signature D.A. Rau

Notes:

3. The original aluminum pump was replaced with a stainless steel pump prior to calibration on 8/6/65.

Figure 3. Calibration sign-off record

Calibration Record
Davis Instruments Hydrogen Fluoride Detector
Model 11-7010-RP-Special

Procedure No. FLOX-00517 Instrument Serial No. 65-161

Sample Flowrate 2.0 cfh Water Flowrate 4.0 cc/min.

Hydrogen Fluoride Standard 70 ppm HF

Recorder Output 19.4 div. Instrument Factor 3.6 ppm HF/div

Date 6/23/65 Signature D.A. Rau

Sample Flowrate 1.3 cfh Water Flowrate 4.0 cc/min.

Hydrogen Fluoride Standard 24.5 ppm HF

Recorder Output 12.0 div. Instrument Factor 2.0 ppm HF/div

Date 7/1/65 Signature D.A. Rau

Sample Flowrate 2.0 cfh Water Flowrate 4.0 cc/min

Hydrogen Fluoride Standard 53 ppm HF

Recorder Output 16.5 div. Instrument Factor 3.2 ppm HF/div

Date 8/6/65 Signature D.A. Rau

Notes:

1. On 6/9/65, the pump flowrate was insufficient to achieve the proper sample and water flowrates. The pump was removed and cleaned; the pump face appeared pitted and corroded slightly. After re-assembling, standard sample and water flowrates were achieved.
2. On 7/1/65, the recorder resistor was removed prior to instrument calibration. Due to pump malfunction, the maximum sample flow was 1.3 cfh, at 4.0 cc/min water flowrate.

Figure 3. Calibration sign-off record

Calibration Record
Davis Instruments Hydrogen Fluoride Detector
Model 11-7010-RP-Special

Procedure No. FLOX-00517 Instrument Serial No. 65-161

Sample Flowrate 2.0 cfh Water Flowrate 4.0 cc/min

Hydrogen Fluoride Standard 147 ppm HF

Recorder Output 44.4 div. Instrument Factor 3.3 ppm HF/div

Date 8/30/65 Signature D.A. Rau

Sample Flowrate 2.0 cfh Water Flowrate 4.0 cc/min

Hydrogen Fluoride Standard 90 ppm HF

Recorder Output 25.2 div. Instrument Factor 3.5 ppm HF/div

Date 8/30/65 Signature D.A. Rau

Sample Flowrate ______ Water Flowrate ______

Hydrogen Fluoride Standard ______ ppm HF

Recorder Output ______ div. Instrument Factor ______ ppm HF/div

Date ______ Signature ______

Notes:

3. On 7/16/65, calibration was attempted, but no sample flow could be obtained due to pump malfunction.
4. The original aluminum pump was replaced with a stainless steel pump prior to calibration on 8/6/65.

Figure 3. Calibration sign-off record

Calibration Record
Davis Instruments Hydrogen Fluoride Detector
Model 11-7010-RP-Special

Procedure No. FLOX-00517 Instrument Serial No. 65-162

Sample Flowrate 2.0 cfh Water Flowrate 4.0 cc/min.

Hydrogen Fluoride Standard 138 ppm HF

Recorder Output 29.5 div. Instrument Factor 4.7 ppm HF/div

Date 6/9/65 Signature D.A. Rau

Sample Flowrate 1.5 cfh Water Flowrate 4.0 cc/min.

Hydrogen Fluoride Standard 24.5 ppm HF

Recorder Output 5.9 div. Instrument Factor 4.1 ppm HF/div

Date 7/1/65 Signature D.A. Rau

Sample Flowrate 2.0 cfh Water Flowrate 4.0 cc/min

Hydrogen Fluoride Standard 53 ppm HF

Recorder Output 19.7 div. Instrument Factor 2.7 ppm HF/div

Date 8/6/65 Signature D.A. Rau

Notes:

1. On 6/10/65, with standard sample and water flowrates, 24 ppm F_2 gave 10.5 divisions recorder output, or a sensitivity of 2.3 ppm F_2/div.
2. On 7/1/65, the recorder resistor was removed before instrument calibration. At 4.0 cc/min, the sample flow maximum was 1.5 cfh.
3. On 7/16/65, calibration was attempted, but no sample flow could be obtained, due to pump malfunction.

Figure 3. Calibration sign-off record

Calibration Record
Davis Instruments Hydrogen Fluoride Detector
Model 11-7010-RP-Special

Procedure No. FLOX-00517 Instrument Serial No. 65-162

Sample Flowrate 2.0 cfh Water Flowrate 4.0 cc/min

Hydrogen Fluoride Standard 147 ppm HF

Recorder Output 44.8 div. Instrument Factor 3.3 ppm HF/div

Date 8/30/65 Signature D.A. Rau

Sample Flowrate 2.0 cfh Water Flowrate 4.0 cc/min

Hydrogen Fluoride Standard 90 ppm HF

Recorder Output 27.2 div. Instrument Factor 3.3 ppm HF/div

Date 8/30/65 Signature D.A. Rau

Sample Flowrate ______ Water Flowrate ______

Hydrogen Fluoride Standard ______ ppm HF

Recorder Output ______ div. Instrument Factor ______ ppm HF/div

Date ______ Signature ______

Notes:

4. On 8/6/65, the original aluminum pump was replaced with a stainless steel pump prior to calibration.

APPENDIX V

NON-COMBUSTIVE LOX SPILL TEST PROCEDURE 00514

NON-COMBUSTIVE LOX SPILL

TEST PROCEDURE

00514

FLOX

PREPARED BY:

CHECKED BY:

APPROVED BY: 6-11-5

APPROVED ~~BY:~~

APPROVED BY:

FLOX
RELEASED
DATE 6/28/65
CHG. LETTER —

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LOX SPILL TEST NO._____

1.0 SCOPE

This procedure provides for the non-combustive LOX spill and evaporation tests at S-2 (TCP 8402). The procedure is to be utilized to secure LOX diffusion and evaporation rate from each of the four (4) FLOX spill pits. The addition of tracer material and smoke tracking is to be accomplished by Meteorology Research, Inc. to provide meteorological record of the LOX diffusion. All data from the LOX spill tests is to be integrated with the subsequent FLOX spill data to complete the FLOX spill meteorological study.

2.0 PREPARATION

1. Accomplish steps in Sect. I, IIA thru IID, and III-1 thru III-23 of LO_2 Flow Procedure - FLOX Test Stand FLOX-00515,
2. Proceed from Sect IV, Step 12 of LO_2 Flow Procedure - FLOX Test Stand FLOX-00515.
3. Verify all recorders and thermocouples have been calibrated.
4. Verify installation of FLOX spill pit line from spill valve F-70 and the ______ pit.
5. Verify water systems ready.
6. Verify that the system is as described by FLOX schematic 00015J with cold flow procedure modifications.
7. Verify that spill basin to be used is clean and dry i.e., free from all debris and visible moisture.
8. Dryer and moisture monitor operating (below -85°F dew point).
9. Verify data sheet ready.

3.0 TEST PROCEDURE

Check meteorological condition and make decision to test. (Program Office)
Notify Sycamore Control of test preparation.

2:00 Hours to Test Start

1. Set up FP sensors. (Florescent particles)
2. Set up cameras and take test shot.
3. Start wind and temperature recordings. (M.R.I.)
4. Alert aircraft (M.R.I.) of start of test.

3.0 TEST PROCEDURE - Continued

5. Verify FLOX facility ready (Para. 2.0).

6. Record slug tank LOX level. ________

7. Verify instrumentation ready.

1:00 Hours to Test Start

8. Verify cameras ready.

9. Notify S-2 security of Test Plan and status.

10. Verify smoke generator and tracer injection system ready.

0.45 Hours to Test Start

11. Verify the status of the F.P. sensor installation (M.R.I.).

0:30 Hours to Test Start

12. Aircraft take-off (M.R.I. to phone)

NOTE: Hold can be initiated at this point, max, 2:00 hours,

13. Close access road - clear area of observers, and set condition "Red".

0:10 Hours to Test Start

14. Close F11

15. Increase H12 to 10 $\pm$ 5 psig. (Monitor P11)

16. Open (energize) SH12.

17. Open H1 (Maintain 10 $\pm$ 5 psig blanket pressure on tank).

0:05 Hours to Test Start

18. Take reading on meteorological conditions. (Final decision to test). (Program Office)

19. Verify aircraft in area.

20. Locate personnel for test.

21. Turn on spill pit level recorders.

3.0 TEST PROCEDURE - Continued

22. Open F-23

0:01 Hours to Test Start

23. Start sequence cameras.

0:00 Hours to Test Start

24. Open F-70

25. Close F-7

26. Open F-5. Record Delta P reading and time. ________

27. Slowly increase N49 setting to 30 psig. Allow tank to come to this pressure.

28. Record Delta P reading and time when each pit thermocouple is wet with LO_2.

29. Note LOX rise in pit and close F-9 when level reaches ______ or ______ pounds in pit.

30. Close F-70, close F-5, open F-7, release smoke.

31. Close H12 and vent tank to 10 psig.

32. Release tracer material (after evaporation is established)

33. Record time of temperature rise of each thermocouple in pit.

34. Shut down recorders.

35. Recover FP samples.

4.0 SYSTEM DRAIN AND PURGE

1. Slowly increase N49 setting until 150 $\pm$ psig is reached.

2. Open F-5 and F-7. Drain LO_2 until He purges transfer line.

3. Close F-5.

4. Open N-14 and N-64 and purge transfer line for one minute. Close W14.

5. Back off regulator N49 to 10 $\pm$ 5 psig. Close SH12.

6. Open F-11 and vent tank to 10 $\pm$ 5 psig.

7. Close F-10, F-5, F-7 and F-9.

4.0 SYSTEM DRAIN AND PURGE - Continued

8. Close H-1, H-2 and H-13.

9. Secure LO_2 transfer system.

10. Secure FLOX system.

11. Area warning to condition green.

12. Secure instrumentation system.

APPENDIX VI

FLOX COLD SPILL TEST PROCEDURE 00523

GENERAL DYNAMICS/CONVAIR

FLOX COLD SPILL

TEST PROCEDURE

FLOX-00523

FLOX

Prepared by: J A Roberts

Checked by: R. L. Barrows

Approved by: J. R. Thayer

Approved by: F. Dilazza

Approved by: E. P. Stone
533-3

FLOX
RELEASED R. L. Barrows
DATE 6/28/65
CHG. LETTER____

TABLE OF CONTENTS

*If four (4) or more hours have lapsed since accomplishment of FLOX Storage Tank Fill and Mix Procedure, FLOX-00522, perform these sections.

If less than four (4) hours have lapsed proceed directly to Section V.

I SCOPE

This procedure is to accomplish the transfer (FLOX Cold Spill) of ________ pounds of 30% FLOX misture from the FLOX Storage Tank to one of the four FLOX evaporation pits. A series of three such tests will be performed. Data will be collected to determine equilibrium boil off rates and cold cloud diffusion characteristics.

II STAND PREPARATION

1. The site shall be in the configuration shown on Schematic-Fluid Flow FLOX Test Stand - FLOX-00015J.
2. Verify the following procedures accomplished:
   a. FLOX Test Stand Leak and Functional Test Procedure, FLOX-00512.
   b. FLOX Test Stand Fluorine Passivation Procedure, FLOX-00513.
   c. LO_2 Flow Procedure FLOX Test Stand, FLOX-00515.
   d. Non-Combustive LO_2 Spill Test Procedure, FLOX-00514.
   e. FLOX Storage Tank Fill and Mix Procedure, FLOX-00522.
3. Verify all temporary passivation plumbing removed and capped - e.i., F-50 valve and its connections.
4. Verify FLOX flow line to LO_2 dump through F-7 removed and plumbing restored per schematic.
5. Verify the following configuration:
   a. H-5 capped.
   b. F-39 capped.
   c. Spool piece between FLOX Vaporizer and F-5 installed.
   d. Spool piece in Test Cell, and sample bottle installed.
   e. Test Cell vent line blind flange installed closed.
   f. Blind flange between catch tank and vent burner open.
   g. Liquid fill and tank vent connections capped.
   h. Line between H24 and F128 removed and capped.
   i. Line between F70 and ____________ pit installed.
6. All personnel involved with this procedure are to be familiar with "GD/C Fluorine (FLOX) Safety Rulesaand Regulations", outfitted accordingly, and operate in the prescribed manner.

II STAND PREPARATION - Continued

7. Verify that facility GN_2 and He supply is adequate and has been certified to be within accepted limits.
8. Verify Firex water supply is adequate.
9. Verify Blockhouse GN_2 "K" bottle pressure 500-2200 psig.
10. Verify adequate charcoal level in vent burner.
11. Verify that gage panel TV camera and monitor have been checked out and that lighting conditions are adequate for good readability in the blockhouse.
12. Verify system pressurized to 10 ± 5 psig.

III LN_2 FILL/TOP OFF - FLOX STORAGE TANK LN_2 JACKET

1. Set GN308 pressure regulator to 10 ± 5 psig.
2. Monitor pressure on gauge G310A.
3. Close LN302, LN_2 tank vent valve.
4. Verify vent switch on pneumatics control panel in off position.
5. Position LN_2 storage tank pressure/vent switch to pressure position.
6. Remove pipe cap from pressurizing valve after tank starts pressurizing.
7. Verify LN-107 valve open.
8. Slowly open LN_2 storage tank shutoff valve LN-100.
9. Open N16 and fill LN_2 jacket until level is between LN_2 Full and LN_2 Overfill float switches.
10. Close N-16 and LN-107 (Caution: Work Step 11 immediately).
11. Open LX-430 (LN_2 supply vent valve).
12. Allow slug tank LN_2 jacket temperature to stabilize for 30 minutes.
13. Open LN-107.
14. When LN_2 flows from LX-430, close this valve and open N-16.
15. Top off LN_2 jacket until LN_2 overflows.
16. Close N-16 and LN-100.
17. Open LX-430 until LN_2 is boiled out of supply line.

III LN_2 FILL/TOP OFF - FLOX STORAGE TANK LN_2 JACKET - Continued

18. Position LN_2 storage tank press/vent switch to vent position.
19. Open LN_2 vent valve LN-302.
20. Replace pipe cap removed in step 6.

IV RESUPPLY - FLOX STORAGE TANK

This section is to be used to resupply the FLOX tank when there is a residual left from previous testing.

1. Obtain reading on FLOX Concentration Monitor. It is % F_2 = ___________.
2. Obtain present Delta P reading. It is V_i = ___________ volts.
3. Enter Delta P calibration chart with V_i. Read corresponding present weight of FLOX mixture. $\#FLOX_i$ = ___________#.
4. Calculate present weight of LF_2; $\#F_{2i}$ = % F_2 x $\#FLOX_i$ = ___________#.
5. Calculate present weight of LO_2; $\#O_{2i} = \#FLOX_i - \#F_{2i}$ = ___________#.
6. Determine desired weight of FLOX; $\#FLOX_f$ = ___________#.

*7. Calculate final weight of fluorine LF_2; $\#F_{2f} = .30 \times \#FLOX_f$ = ___________#.

8. Calculate final weight of LO_2; $\#O_{2f} = \#FLOX_f - \#F_{2f}$ = ___________#.
9. Calculate weight of LO_2 to be added $\#O_{2a} = \#O_{2f} - \#O_{2i}$ = ___________#.
10. Calculate weight in tank after LO_2 addition $\#FLOX_a$ = $\#FLOX_i + \#O_{2a}$ = ___________#.
11. Enter Delta P calibration chart with $\#FLOX_a$. Read corresponding voltage. V_a = ___________VOLTS.
12. Enter Delta P calibration chart with $\#FLOX_f$. Read corresponding voltage. V_f = ___________VOLTS.

* 30% FLOX mixture is assumed.

CAUTION

ALWAYS ADD LO_2 BEFORE ADDING LF_2

IV RESUPPLY - FLOX STORAGE TANK - Continued

13. LO_2 Resupply:
Repeat section V, Steps 1 thru 30 of FLOX Storage Tank Fill and Mix Procedure - FLOX-00522.

Use the voltage obtained in this Section, Step 2 in lieu of the voltage and pounds specified in Section VA Step 21 of FLOX-00522.

14. LF_2 Resupply:
Repeat Section VI Steps 1 thru 77 of FLOX Storage Tank Fill and Mix Procedures, FLOX-00522.
Use the voltage obtained in this section step 12 in lieu of the voltage and pounds specified in Section VI Step 44 of FLOX-00522.

V FLOX COLD SPILL TEST

Check meteorological condition and make decision to test. (Program Office). Notify Sycamore control of test preparation.

2:00 Hours to Test Start

1. Set up FT sensors. (Fluorescent particles)
2. Set up cameras and take test shot.
3. Start wind and temperature recordings. (M.R.I.)
4. Alert aircraft (M.R.I.) of start of test.
5. Verify FLOX facility ready (Para. 2.0).
6. Record slug tank LOX level.
7. Verify instrumentation ready.

1:00 Hours to Test Start

8. Verify cameras ready.
9. Notify S-2 Security of test plan and status.
10. Verify smoke generator and tracer injection system ready.

0:45 Hours to Test Start

11. Verify the status of the F.P. sensor installation (M.R.I.).

0:30 Hours to Test Start

12. Aircraft take-off (M.R.I. to phone).

NOTE: Hold can be initiated at this point, max, 2:00 hours and set condition "RED".

13. Close access road - clear area of observers.
14. Verify sample bottle valves are open; F-42, F-25 & F-3 closed.

V FLOX COLD SPILL TEST - Continued

0:10 Hours to Test Start

15. Verify close F-11.
16. Verify increase H-12 at 10 ± 5 psig. (Monitor Pl 1).
17. Verify open (energized) SH12.
18. Verify open H-1 (Maintain 10 ± 5 psig blanket pressure on tank).
19. Verify open F-10.
20. Open F-23 and F-9.
21. Open F-25 and F-7 and flow through sample bottle for 2 minutes.
22. Close F-7 and increase storage tank to ____________ psig.
23. Close F-25.
24. Vent storage tank to 10 ± 5 psig blanket pressure, close F-23.
25. Close sample bottle valves.
26. Open valve F-42 and F-7 to vent 30 psig from lines.
27. Close F-7 and F-9.
28. Open F-5.

0:05 Hours to Test Start

29. Take reading on meteorological conditions. (Final decision to test). (Program Office)
30. Verify aircraft in area.
31 Locate personnel for test.
32. Turn on spill pit level recorders.
33. Open F-23.

0:01 Hours to Test Start

34. Start sequence cameras.

0:00 Test Start

35. Open F-70. Record Delta P reading and time ____________.
36. Slowly increase N-49 setting to 30 psig. Allow tank to come to this pressure.
37. Record Delta P reading and time when each pit thermocouple is wet with FLOX.
38. Note FLOX rise in pit and close F-5 when level reaches ____________ or ____________ pounds in pit.

V FLOX COLD SPILL TEST - Continued

39. Close F-70, close F-5, open F-6.
40. Close H-12 and vent tank to 10 psig.
41. Release tracer material. (After evaporation is established).
42. Record time of temperature rise of each thermocouple in pit.
43. Shut down recorders.
44. Recover FP samplers.

VI SYSTEM SECURING

1. Slowly increase N-49 setting until 150 ± 5 psig is reached.
2. Open F-5 and F-7. Drain LO_2 until He purges transfer line.
3. Close F-5.
4. Open N-14 and N-64 and purge transfer line for one minute. Close W-14.
5. Back off regulator N-49 to 10 ± 5 psig. Close SH-12.
6. Open F-11 and vent tank to 10 ± 5 psig.
7. Close F-10, F-5, F-7 and F-9.
8. Close H-1, H-2 and H-13.
9. Secure LO_2 transfer system.
10. Secure FLOX system.
11. Area warning to condition green.
12. Secure instrumentation system.

APPENDIX VII

COMBUSTIVE FLOX SPILL TEST PROCEDURE 00524

GENERAL DYNAMICS/CONVAIR

DATE: ____________

"A" ________ LBS 30% FLOX &

________ LBS CHARCOAL/RP

T - 2 HOURS: ________

COMBUSTIVE FLOX SPILL

TEST PROCEDURE

FLOX-00524

REV. A 7/16/65 RLB

Test No ______

FLOX

Prepared by: J.A. Roberts

Checked by: R.L. Barrows

Approved by: S.R. Stone

Approved by: Frank DeBiazzo

Approved by: J.R. Thayer

FLOX
R.L. Barrows
RELEASED
DATE 6 July 65
CHG. LETTER —

TABLE OF CONTENTS

*If four (4) or more hours have lapsed since accomplishment of FLOX Storage Tank Fill and Mix Procedure, FLOX-00522, perform these sections.

If less than four (4) hours have lapsed proceed directly to Section V.

I SCOPE

This procedure is to accomplish the transfer of a 30% FLOX mixture from the FLOX Storage Tank to a temporary holding tank located above FLOX Spill Pad. This tank will be explosively discharged onto the spill pad thereby accomplishing a Hot FLOX Spill. A total of eleven such spills will be performed using various amounts of FLOX as follows:

1 - 100 pound Spill Test

2 - 500 pound Spill Test

1 - 1000 pound Spill Test

7 - 3000 pound Spill Test

II STAND PREPARATION

1. The site shall be in the configuration shown on Schematic-Fluid Flow FLOX Test Stand - FLOX-00015J.
2. Verify the following procedures accomplished:
   a. FLOX Test Stand Leak and Functional Test Procedure, FLOX-00512.
   b. FLOX Test Stand Flourine Passivation Procedure, FLOX-00513.
   c. LO_2 Flow Procedure FLOX Test Stand, FLOX-00515.
   d. Non-Combustive LO_2 Spill Test Procedure, FLOX-00514.
   e. FLOX Storage Tank Fill and Mix Procedure, FLOX-00522.
   f. Non-combustive FLOX Spill Test Procedure, FLOX-00523.
3. Verify all temporary passivation plumbing removed and capped - e.i., F-50 valve and its connections.
4. Verify FLOX flow line to LO_2 dump through F-7 removed and plumbing restored per schematic.
5. Verify the following configuration:
   a. H-5 capped.

II STAND PREPARATION - Continued

b. F-39 capped.

c. Spool piece between FLOX Vaporizer and F-5 installed.

d. Spool piece in Test Cell installed.

e. Test Cell vent line blind flange installed closed.

f. Blind flange between catch tank and vent burner open.

g. Liquid fill and tank vent connections capped.

h. Line between H-24 and F-128 removed and capped.

i. Line between F-70 and Spill Tank installed.

~~j. Shape charge and instrumentation installed.~~ "A"

6. All personnel involved with this procedure are to be familiar with "GD/C Fluorine (FLOX) Safety Rules and Regulations", outfitted accordingly and operate in the prescribed manner.

7. Verify that facility GN2, Helium supply and instrument air are adequate and have been certified to be within accepted limits.

GN2 Pressure: ______________ psig. "A"

Helium Pressure: ______________ psig.

Instrument Air Pressure: ____________ psig.

8. Verify Moisture Monitor reading to be within acceptable limits.

Water content: __________ PPM = ____________ °F. "A"

9. Verify Firex water supply is adequate.

10. Verify Blockhouse GN2 "K" bottle pressure to be between 500-2200 psig.

Blockhouse GN2 Pressure: ____________ psig. "A"

11. Verify adequate charcoal level in vent burner.

12. Verify that gage panel TV camera and monitor have been checked out and that lighting conditions are adequate for good readability in the Blockhouse.

II STAND PREPARATION - Continued

13. Verify system pressurized to 10 ± 5 psig.

14. Verify Spill Tank thermocouples (F11T, F12T and F13T) installed and ready. "A"

15. Place ____________ lbs of charcoal/RP-1 in the spill basin. Place smoke powder and wire mesh on charcoal if required (per Program Office).

16. Verify FLOX Spill Pad "K" bottle pressure to be between 500-2200 psig. "A"

Spill Pad GN2 Pressure: ________________ psig.

III LN_2 FILL/TOP OFF - FLOX STORAGE TANK LN_2 JACKET

1. Set GN-308 pressure regulator to 10 ± 5 psig.
2. Monitor pressure on gauge G310A.
3. Close LN-302, LN_2 tank vent valve.
4. Verify vent switch on pneumatics control panel in off position.
5. Position LN_2 storage tank pressure/vent switch to pressure position.
6. Remove pipe cap from pressurizing valve after tank starts pressurizing.
7. Verify LN-107 valve open.
8. Slowly open LN_2 storage tank shutoff valve LN-100.
9. Open N-16 and fill LN_2 jacket until level is between LN_2 Full and LN_2 Overfill float switches.
10. Close N-16 and LN-107 (Caution: Work Step 11 immediately).
11. Open LX-430 (LN_2 supply vent valve).
12. Allow slug tank LN_2 jacket temperature to stabilize for 30 minutes.
13. Open LN-107.
14. When LN_2 flows from LX-430, close this valve and open N-16.
15. Top off LN_2 jacket until LN_2 overflows.
16. Close N-16 and LN-100.
17. Open LX-430 until LN_2 is boiled out of supply line.
18. Position LN_2 storage tank press/vent switch to vent position.
19. Open LN_2 vent valve LN-302.
20. Replace pipe cap removed in step 6.

FILL & MIX FOR TEST NO. ________. DATE: ________ "A"

IV RESUPPLY - FLOX STORAGE TANK

This section is to be used to resupply the FLOX tank when there is a residual left from previous testing.

1. Obtain reading on FLOX Concentration Monitor.

   It is % F_2 = ____________.

2. Obtain present Delta P reading. It is V_i = ____________ volts.

3. Enter Delta P calibration chart with V_i. Read corresponding present weight of FLOX misture. $\#FLOX_i$ = ____________#.

4. Calculate present weight of LF_2; $\#F_{2_i}$ = % F_2 x $\#FLOX_i$ = ____________#.

5. Calculate present weight of LO_2; $\#O_{2_i} = \#FLOX_i - \#F_{2_i}$ = ____________#.

6. Determine desired weight of FLOX; $\#FLOX_f$ = ____________#.

*7. Calculate final weight of fluorine LF_2; $\#F_{2_f} = .30 \times \#FLOX_f$ = ____________#.

8. Calculate final weight of LO_2; $\#O_{2_f} = \#FLOX_f - \#F_{2_f}$ = ____________#.

9. Calculate weight of LO_2 to be added $\#O_{2_a} = \#O_{2_f} - \#O_{2_i}$ = ____________#.

10. Calculate weight in tank after LO_2 addition $\#FLOX_a$ = $\#FLOX_i = \#O_{2_a}$ = ____________#.

11. Enter Delta P calibration chart with $\#FLOX_a$. Read corresponding voltage. V_a = ____________VOLTS. V_a (actual) = ____________ VOLTS. "A"

12. Enter Delta P calibration chart with $\#FLOX_f$. Read corresponding voltage. V_f = ____________VOLTS. V_f (adjusted) = ____________ VOLTS. "A"

* 30% FLOX mixture is assumed.

CAUTION

ALWAYS ADD LO_2 BEFORE ADDING LF_2

IV RESUPPLY - FLOX STORAGE TANK - Continued

13. LO_2 Resupply:

Repeat Section V, Steps 1 thru 30 of FLOX Storage Tank Fill and Mix Procedure - FLOX-00522.

Use the voltage obtained in this Section, Step 2 in lieu of the voltage and pounds specified in Section VA Step 21 of FLOX-00522.

14. LF_2 Resupply:

Repeat Section VI Steps 1 thru 77 of FLOX Storage Tank Fill and Mix Procedures, FLOX-00522.

Use the voltage obtained in this Section, Step 12 in lieu of the voltage and pounds specified in Section VI, Step 44 of FLOX-00522.

V FLOX HOT SPILL TEST

Check meteorological condition and make decision to test. (Program Office). Notify Sycamore control of test preparation.

2:00 Hours to Test Start (TIME: ____________). "A"

1. Set up FP sensors (Fluorescent particles MRI) and place F2/HF detectors (GD/C).

2. Set up cameras and take test shot.

3. Start wind and temperature recordings. (M.R.I.)

4. Alert aircraft (M.R.I.) of start of test.

5. Verify FLOX facility ready (Para. 2.0).

6. Record slug tank FLOX level. P = ________ V. = ________ lbs 30% FLOX."A

7. Verify instrumentation ready.

8. Install shaped charge.

1.00 Hours to Test Start (TIME: ____________). "A"

9. Verify cameras ready.

10. Notify S-2 Security of test plan and status.

V FLOX HOT SPILL TEST - Continued

11. Verify smoke and tracer injection system ready.

0:45 Hours to Start Test

12. Verify the status of the F.P. sensor installation (M.R.I.) and F2/HF detectors (GD/C).

0:30 Hours to Start Test

13. Aircraft take-off (M.R.I. to phone).

14. Close access road and clear area of observers. "Y" point in condition "Red". Time: ____________ . "A"

0:10 Hours to Start Test

15. Verify F-11 closed.

16. Verify PI-1 at zero psig. "A"

17. Verify H-1 opened. "A"

18. Turn nozzle water full on (W-1 and W-2).

19. Open F-10.

20. Turn T-Barrel Heater on (if required).

21. Open water valve near exit of spill tank vent line.

22. Take FLOX sample (if required).

    a. Open F-23 and F-9.

    b. Open F-7.

    c. Open F-25 and increase PI-1 to 15 psig. "A"

    d. After 5 minutes of flow, close F-7 and then close F-25.

    e. Close H-12 and open F-11 to vent PI-1 to zero.

    f. Secure T-Barrel Heater and FLOX sample.

    g. Close F-9 and Open F-5.

0:05 Hours to Start Test

23. Verify aircraft in area.

V FLOX HOT SPILL TEST - Continued

24. Take reading on meteorological conditions (Final decision to test by Program Office).

    Time: ____________ "A"

    Wind Heading: ____________

    Wind Speed: ____________ MPH.

    Other conditions: ____________

25. Locate personnel for test.

26. Turn on spill tank level recorders (F11T, F12T, and F13T) "A"

27. Open F-23 and F-5.

    0:00 Test Starts

28. Open F-70. Record Delta P reading and time.

    Time: ____________ "A"

    Delta P: ____________ = ____________ lbs 30% FLOX

29. Open H-12 and slowly increase N-49 setting to 10 psig. Allow tank to come to this pressure. Accomplish F-70 chilldown at 10-15 psig on PI-1.

30. Record Delta P reading and time when each spill tank thermocouple is wet with FLOX.

    F11T (#): ____________ at ____________. "A"

    F12T (#): ____________ at ____________.

    F13T (#): ____________ at ____________.

31. Note FLOX rise in spill tank and close F-23 when level reaches ____________ thermocouple. "A"

32. Close F-70 approx. one (1) minute after closing F-23. "A"

33. Close H-12 and vent tank to 10 psig.

34. Take reading on meteorological conditions. Hold if necessary until conditions are favorable to testing (per Project Office). "A"

V FLOX HOT SPILL TEST - Continued

35. Begin two (2) minutes countdown. Time: ______________.

a. T - 15 sec. - release tracer material. "A"

b. T - 2 sec. - start cameras.

c. T - 0 sec. - actuate shape charge. Time: ______________.

36. After initial fire ball, and mixture starts burning fuel rich, turn on water deluge until fire is quenched.

37. Shut down recorders. (At Test Conductor discretion).

38. Recover F.P. samplers.

39. Recover F2/HF instrumentation.

VI SYSTEM SECURING

1. Open N-64 and purge transfer line thru F-6 for one (1) minute, then open F-70, close F-6 and purge for five (5) minutes. After 5 minutes, secure spill fog and continue purge for another five (5) minutes, then close F-70. When PI-4 reaches 10 psig, close N-64.

2. Purge sample system for five (5) minutes (if required). "A"

3. Back off regulator N-49 to 10 ± 5 psig. Close SH-12.

4. Open F-11 and vent tank to 10 psig.

5. Close F-10, F-5 and F-6. Open F-9.

6. Close H-1 and H-2.

7. Secure instrumentation system.

8. Record final Delta P and time.

Time: __________________.

Delta P: __________________ = ______________ lbs 30% FLOX. "A"

9. Area warning to condition "Green". Time: ______________. "A"

10. Secure FLOX system.

METEOROLOGICAL SURVEY AND TRACER DIFFUSION EXPERIMENTS AT SYCAMORE CANYON

Final Report

to

General Dynamics/Convair
San Diego, California

Purchase Order No. B161682

by

T. B. Smith
K. M. Beesmer
R. L. Miller

Meteorology Research, Inc.
2420 North Lake Avenue
Altadena, California

30 November 1965

MRI65 FR-308

SUMMARY

A series of 27 tracer trials was conducted at Sycamore Canyon during the period of April through October 1965. Fluorescent particles (FP) were released from the S-2 site to simulate potential releases of toxic material. Sampling of the material was conducted on three crosswind sampling lines to a distance of one and one-half miles from the release. A few samplers were operated for several of the trials at a distance of about five miles from the release.

Data from 17 of the tracer trials could be used for an evaluation of the diffusivity characteristics of the Sycamore Canyon area. In 11 trials FP material was entrained into the rising smoke cloud produced by an artificially generated heat source. For nine of these trials another color of FP material was released a few minutes before or after the hot source to serve as a control which would be unaffected by the motion of the buoyant cloud.

Meteorological instrumentation was added to the S-2 gantry tower to measure wind speed, turbulence and vertical temperature gradient. In addition, a light aircraft made vertical soundings of temperature, beginning at the top of the tower and extending upward to 3000 feet MSL. A sounding was made immediately before and immediately after each release. The aircraft also provided an observing platform for photographing the smoke cloud at successive intervals after the release.

An analysis of the cold source diffusion trials indicated that the downwind dosages were consistently less than calculated by existing models such as the WIND equation. In addition, the ensemble of maximum dosages for all trials showed much greater variability with distance than is customarily found in diffusion programs. These lower dosages and observed variability are attributed to the elevated nature of the cloud as it passes over the downwind sampling array. It

is suggested that the heated slope immediately downwind (east) of the S-2 site provides a means for carrying the cloud upward to a level considerably higher than would have occurred in flat terrain.

FP releases with hot source clouds showed lower dosages at the first sampler line (first downwind ridge) than those observed with the cold clouds. At the second ridge, however, the dosages were comparable for the two source types. The data indicate that the hot clouds have greater buoyancy than those from cold sources when passing over the first ridge. Further downwind, for the heat sources involved in the present program, the inversion restricts both cold and hot clouds to approximately the same path.

The FP test data indicate that the median dosage at the eastern boundary of the Sycamore Canyon property for a 100-pound F_2 release should be about 0.08 ppm-min. Ninety per cent of the dosages should be less than 0.33 ppm-min for the range of meteorological conditions experienced during the present program. Under the existing NASA criteria for acceptable dosages, a 6000-pound release of F_2 would produce a median dosage of five ppm-min at the boundary. A release of 1500 pounds would result in a 90 per cent expectancy of the dosage being below five ppm-min. If the contaminant is considered to be HF at the boundary, the allowable releases would be increased to 30,000 pounds and 7500 pounds, respectively.

Partial penetration of the existing inversion was achieved on each of the hot sources involving 3000 pounds of oxidizer. Additional data from the Saturn S-IV test at Edwards AFB indicate that a source of this magnitude would penetrate about half of the inversions with heights below 1800 feet (above the site) but would penetrate nearly all of the inversions below 800 feet.

PART 2

No trials were carried out in the present program with an inversion below 800 feet above the site (1500 feet MSL). Lower inversions should result in increased dosages near the boundary and it is suggested that this condition be avoided in cases where the potential release might be large. Further meteorological restrictions (considered to be of a secondary nature) are that winds should be greater than 2.5 miles per hour, directions from the southwest to northwest and trials conducted between 10 A.M. and 4 P.M. to obtain maximum utility from the heated slope downwind of the S-2 site.

TABLE OF CONTENTS

I. INTRODUCTION

Prospective use of Sycamore Canyon for LF_2/LO_2 testing requires an evaluation of the toxic hazards which might result from the operations. Information is needed on the possible concentrations of toxic material at various nearby populated areas as a function of release amounts, release mode and environmental conditions. Additional data are then required on the frequency of occurrence of specific meteorological conditions so that an estimate of the annual potential utilization of the site can be obtained.

The downwind concentration from an isolated source is a function of distance, terrain, wind and temperature stability. Simulant releases of nontoxic material can be made from the site under study but must be limited in number by economic factors. Diffusion studies covering the wide range of possible parameter variations would lead to a prohibitively large field program.

Numerous field diffusion studies have been carried out in the past in a variety of terrains, winds and temperature conditions. Results of these show considerable variation in concentrations at a given distance downwind from the release. It is one of the purposes of the present study to evaluate Sycamore Canyon with respect to this existing background of data so that an understanding of the diffusion capabilities of the Canyon can be obtained without the undue expense of repeated trials under a wide variety of environment conditions. This has been accomplished by carrying out a smaller number of trials but with added emphasis on the comparison of each trial with known results from other areas.

One area for which comparative field data are not available is the diffusion downwind from a hot source. This problem can be divided into an early stage of motion dominated by the buoyancy of the cloud and a later stage which more closely resembles typical diffusion although an elevated source is created by the cloud buoyancy. In this case, the approach has been to evaluate the buoyant stage in terms of the physical mechanisms involved so that the height of rise might be predicted. Thereafter, the diffusion downwind proceeds in a more normal fashion.

Field observational data from the hot source studies comprise the more important information generated in the present program since there are few such data available. Although insufficient in number to provide the comprehensive understanding desired, the results of the available trials are consistent enough to form reasonable judgments on the utility of the Sycamore Canyon site.

II. TEST DESIGN AND SCOPE

A series of tracer studies was carried out at Sycamore Canyon between April and October 1965 for the purpose of evaluating the diffusion characteristics of the area under possible LF_2/LO_2 mixture source configurations. These studies consisted of three principal phases:

A. Diffusion Environment Trials

Tracer material was released at S-2 and sampled downwind at two crosswind sampling lines. No oxidizer releases were made during this series. Purpose of the releases was to evaluate the diffusion characteristics of the site in comparison with previous field experiments. Seven releases were carried out in this phase. The duration of the release ranged from 30-75 seconds.

B. Cold Source Trials

Tracer material was released from the S-2 area during the process of LO_2 or LF_2/LO_2 mixture boil-offs. The release of the tracer was positioned where the material would be entrained in the LO_2 or LF_2/LO_2 mixture cloud. The early releases in this series were 90 seconds in duration but were later increased to 10 minutes. Sampling of the tracer cloud was accomplished at several crosswind lines at distances to 1.5 miles from the release. Five trials were carried out in this series simultaneously with LO_2 and two with LF_2/LO_2 mixture.

C. Hot Source Trials

Tracer material was released at S-2 in a manner designed to permit the material to be entrained into the rising hot cloud. During the early trials the tracer releases were about 15 seconds in duration, beginning about five seconds prior to ignition. Later in the program, a high-pressure disseminator was fabricated which provided a near-instantaneous source. Ten simultaneous tracer-LF_2/LO_2 mixture hot source trials were conducted during the program. For the last eight of these trials, two types of tracer material were released, one with the rising hot cloud and one about ten minutes later. Purpose of the later dissemination was to acquire comparative diffusion data for a cold cloud to use in obtaining a better evaluation of the effects of the hot source.

Three other tracer trials were conducted during the program. On 25 June, a scheduled LF_2/LO_2 mixture trial was cancelled but the tracer trial was carried out. Results of the trial have been evaluated and are useful in adding to the knowledge of the diffusion characteristics of the area. On 3 September a tracer trial was scheduled to compare simultaneous releases from the 15-second and instantaneous disseminators. The wind was not favorable for this trial and the 15-second release alone was made. On 12 October this trial was repeated for the purpose of comparing disseminators and of obtaining additional diffusion data over a longer travel distance than previous trials had involved.

These trials, together with the eight releases made near but not simultaneous with the hot source trials, provide additional data on environmental diffusion characteristics in the area. As a result, a total of 17 trials has provided information for this portion of the study.

In order that the downwind trajectories and diffusion characteristics of the trials could be visualized more fully, a considerable use was made of smoke releases. The smoke sources varied from Chemical Corps M-2 generators to smoke grenades. Extensive photographs were taken of the smoke releases and used to compare with trajectories determined from the tracer sampling network.

A summary of the tracer test schedule is shown in Table I:

TABLE I

TRACER TEST SCHEDULE

Trial Number	Date (1965)	Release Time (PDT)	Duration (secs)	Trial Description
1	27 April	1815	75	Tracer only
2	28 April	1123	30	Tracer only
3	28 April	1307	80	Tracer only
4	28 April	1405	30	Tracer only
5	28 April	1603	30	Tracer only
6	29 April	1057	40	Tracer only
7	29 April	1305	35	Tracer only
8	8 June	1450	90	Cold LO_2
9	9 June	1310	95	Cold LO_2
10	11 June	0950	140	Cold LO_2
11	14 June	1458	590	Cold LO_2
12	17 June	1009	610	Cold LO_2
13	24 June	1219	495	Cold LF_2/LO_2 mix
14	24 June	1642	495	Cold LF_2/LO_2 mix
15	25 June	1335	900	Tracer only
19	8 July	1340	15	500 lbs LF_2/LO_2 mix
20	12 July	1529	15	2000 lbs LF_2/LO_2 mix
21	19 July	1459.1510	15 (Y.G)	2000 lbs LF_2/LO_2 mix
22	21 July	1302,1316	15 (Y,G)	500 lbs LF_2/LO_2 mix-RP
23	27 July	1019,1030	15 (Y,G)	1000 lbs LF_2/LO_2 mix-RP
24	30 July	1337,1347	15 (Y,G)	2500 lbs LF_2/LO_2 mix
25	4 August	1304,1302	I(Y),15(G)	3000 lbs LF_2/LO_2 mix
26	9 August	1031,1033	I(Y),15(G)	3000 lbs LF_2/LO_2 mix
27	31 August	1006.1009	I(Y),15(G)	3000 lbs LF_2/LO_2 mix
28	3 Sept	0942,0940	I(G),15(Y)	3000 lbs LF_2/LO_2 mix
29	3 Sept	1407		Tracer only
31	12 October	1437,1419	I(Y),15(G)	Tracer only

Notes: 1. Y and G refer to yellow and green FP.

2. I refers to instantaneous release with high-pressure disseminator.

III. INSTRUMENTATION

A. Meteorological

A map of the Sycamore Canyon area is shown in Fig. 1. Also shown are locations of all available meteorological instrumentation.

The anemometer at the GD Meteorology Site is of the Beckman-Whitley type giving wind speed and direction. The instrument is at an elevation of 1100 feet MSL and offers the best exposure to the general flow over the test area.

The MRI VectorVane on the ridge to the northeast of S-2 was installed on a 30-foot tower (Fig. 2). Wind speed and direction were available from this unit on test days.

The MRI VectorVane on the S-2 gantry tower was located at an elevation of 851 feet MSL and 118 feet above the base of the tower. Wind speed and direction were recorded from this unit as well as a vertical turbulence value. A temperature difference (ΔT) was also available from the tower between the levels of 43 and 118 feet.

A GD Aerovane anemometer was also located at the S-2 site at a level of about 60 feet above the base of the tower. A considerable amount of past wind data was available for this location as well as during test periods.

The Aerovane, lowest of the wind units, still did not measure the wind adequately near the ignition pad. Low-level wind observations of a visual nature and smoke trajectories indicated frequent, substantial deviations from the Aerovane and the VectorVane wind on the tower.

B. Tracer System

The tracer selected to simulate the oxidizer cloud was cadmium zinc sulfide (FP), a fluorescent powder with mean particle size near two to three microns diameter. Two

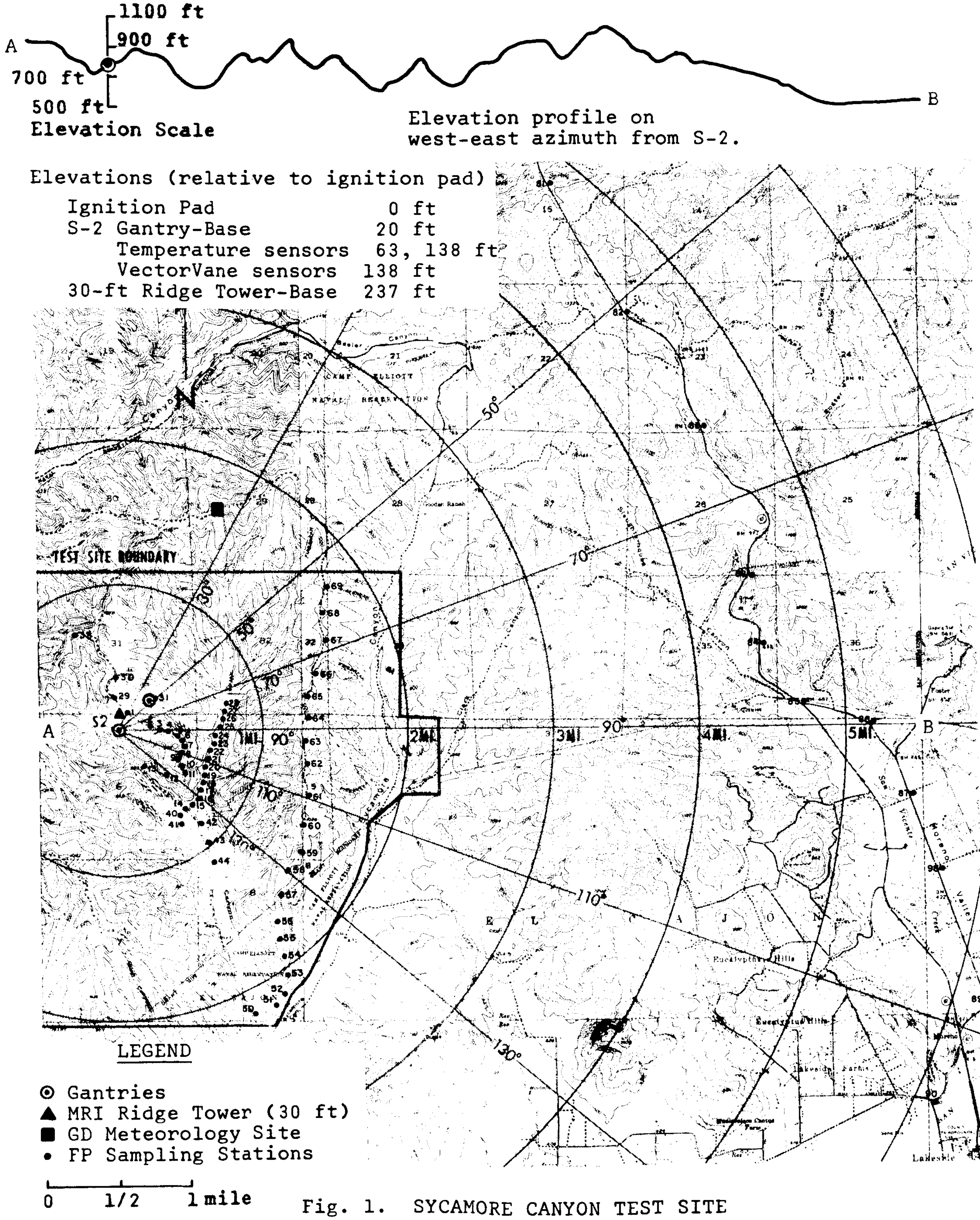
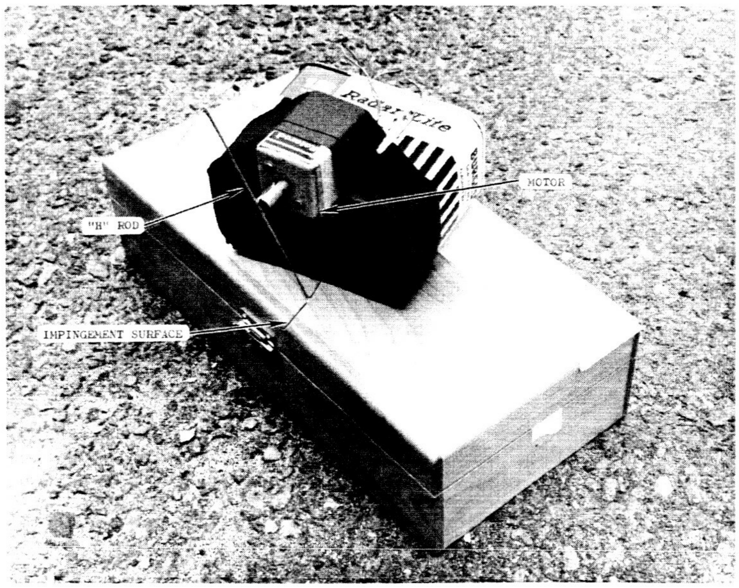
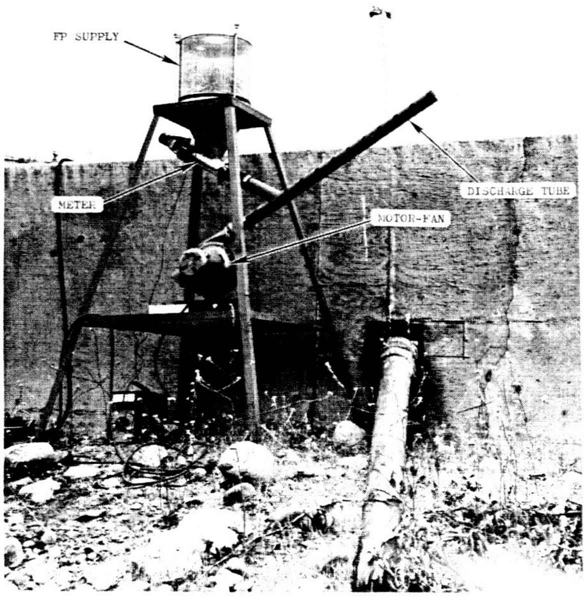


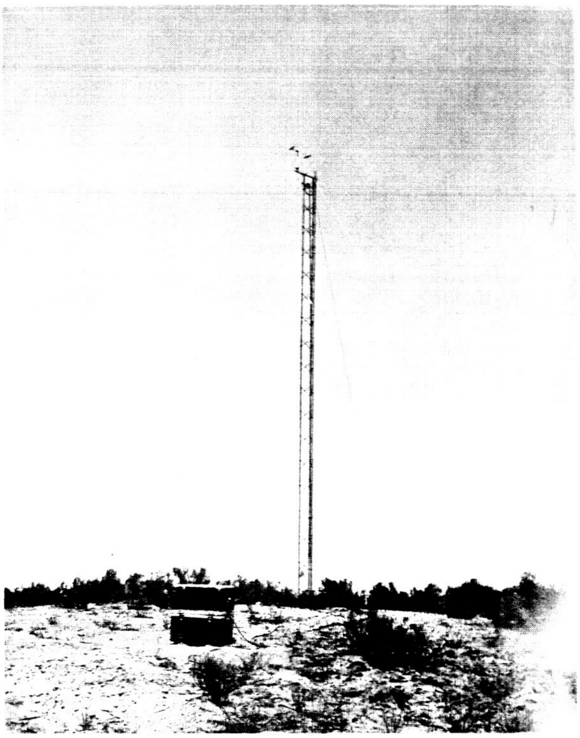
Fig. 1. SYCAMORE CANYON TEST SITE



METEOROLOGY RESEARCH, INC.
ROTOROD ASSEMBLY



METEOROLOGY RESEARCH, INC.
FLUORESCENT PARTICLE DISSEMINATOR



METEOROLOGY RESEARCH, INC.
VECTORVANE ON RIDGE TOWER (30 FT)

Fig. 2. FIELD EQUIPMENT

different FP materials were used at Sycamore Canyon. One of these fluoresced yellow under ultraviolet light and the other green.

The FP material was generally dispensed near the ground with a high speed blower-type disseminator (Fig. 2) whose turbulent velocities break up the powder into individual particles. The material was assayed in the laboratory prior to use in the field and found to have the following characteristics:

	Number FP Per Pound	Mass Mean Diameter
Yellow	6.99×10^{12}	7.98×10^{-4} inches
Green	6.21×10^{12}	8.30×10^{-4} inches

There is a tendency for a small number of the particles to stick together sufficiently so that the turbulent action during dissemination does not separate them. This reduces slightly the effective number disseminated. On the basis of previous field programs, a disseminator efficiency of 75 per cent has been assumed for the blower unit used at Sycamore Canyon. Thus, the effective number of particles released was 5.02×10^{12} per pound for the green.

In normal test use, the disseminator was loaded with a weighed quantity of FP (approximately one pound) and the disseminator started by a remote switch at the appropriate time. The total amount of FP was dispensed in a minimum of about 15 seconds. For the cold source spill, the rate of dissemination was reduced considerably so that the pound of material was disseminated in about 10 minutes.

During the hot source trials it became apparent that a shorter release time, corresponding to the rapid rate of rise of the hot cloud, would maximize the opportunity to inject the FP material into the cloud. A dispenser was fabricated by General Dynamics/Convair personnel which consisted of a tube and a high pressure valve connected to a helium tank. Opening of the valve dispensed the FP in a near-instantaneous source. The dispenser was located immediately downwind of the ignition pad and was activated about four seconds after ignition so that the rapid cooling of the fireball would have occurred prior to dissemination. Inflow of air from the ground levels into the cloud was still occurring at this time and it is considered highly probable that most of the material entered the hot cloud.

No previous experience was available to judge the efficiency of the instantaneous disseminator. It has been assumed that this efficiency is the same as the blower-type disseminator and that the effective number of FP released is the same as given above. A higher efficiency would result in a reduction in the dosages quoted in later sections and conversely for lower efficiencies. It is believed that uncertainties in the instantaneous disseminator efficiency cannot result in an error of more than 30 per cent in the quoted dosages.

Sampling of the FP is accomplished by "rotorod" units (Fig. 2) which have been specifically designed for this purpose by Metronics Associates, Inc. under contract to Dugway Proving Ground. The rotorod sampler consists of small rods made in the form of an "H". These rods are lightly coated with silicone grease. They rotate at a rate of 2400 rpm and collect particles by impaction from the passing air stream. Sampling rates of the rotorod unit are dependent on particle size of the tracer material with smaller particles being collected less efficiently. For the FP material used in the Sycamore Canyon program the effective sampling rate of the rotorod unit is about 0.92 ft^3/min.

Assessment of the FP tracer is carried out by individual counting of particles impacted on the rotorod. This technique requires use of an ultraviolet light and an optical microscope.

The gravity settling rate of the FP is seven to ten feet per hour and can be neglected over the short durations of travel involved in the present program.

C. <u>Aircraft Observations</u>

The temperature structure of the atmosphere above the test site is of critical importance in determining the extent of upward spreading of the cloud during its downwind travel. Height and strength of the inversion play a major role in determining the height of rise of the buoyant cloud.

In order to provide temperature structure data above the top of the S-2 tower, a Piper Apache was used. The aircraft was equipped to record temperature, turbulence and height continuously on a Brush recorder. Flight procedure called for a vertical sounding immediately before and immediately after each trial. Each vertical sounding commenced at the level of the top of the tower and continued in a spiral manner upward over the S-2 site to a height of 3000 feet MSL. Between soundings the aircraft observed and photographed the cloud and followed its travel downwind as long as it remained visible. These photographs for the hot sources have been reconstructed into plan-position maps of the cloud travel and appear later on the dosage maps. Aircraft soundings of temperature and turbulence were reduced at intervals of 100 feet in height and appear in plotted form in a later section.

IV. DIFFUSION ENVIRONMENT

A. Topography

The most prominent terrain feature of western San Diego County is the large coastal mesa which begins near the coast at an elevation of 300 feet, gradually rising to higher elevations, and extending inland 25 miles (Fig. 3). The mesa is cut by narrow, deep river valleys and canyons which generally drain southward or westward toward the sea. The General Dynamics test site is located in West Sycamore Canyon which is oriented in a northwest-southeast direction and is typical of the canyons cutting the mesa. The elevation of the test stand is 713 feet MSL with the canyon walls rising sharply to an elevation more than 200 feet above the site. Thirty to 40 miles inland from the coast, mountains rise to elevations exceeding 6000 feet.

B. Meteorological Environment

1. General

It is generally recognized that the degree of dispersion or dilution of contaminants in the atmosphere is dependent on meteorological factors, primarily wind flow and turbulence. The wind direction establishes the direction in which the material is carried and the speed gives a measure of the amount of air available for diluting the contaminant. Vertical and horizontal mixing through mechanical turbulence is directly related to the roughness of the ground, the wind speed and the stability of the air. The rate of upward dispersion is influenced to a large degree by the low-level thermal stability of the atmosphere. Temperature inversions or thermally stable layers near the earth's surface tend to limit the upward extent to which the material may be dispersed. During periods of low wind speed and low-level inversions, such as occur during night and early morning, contaminants

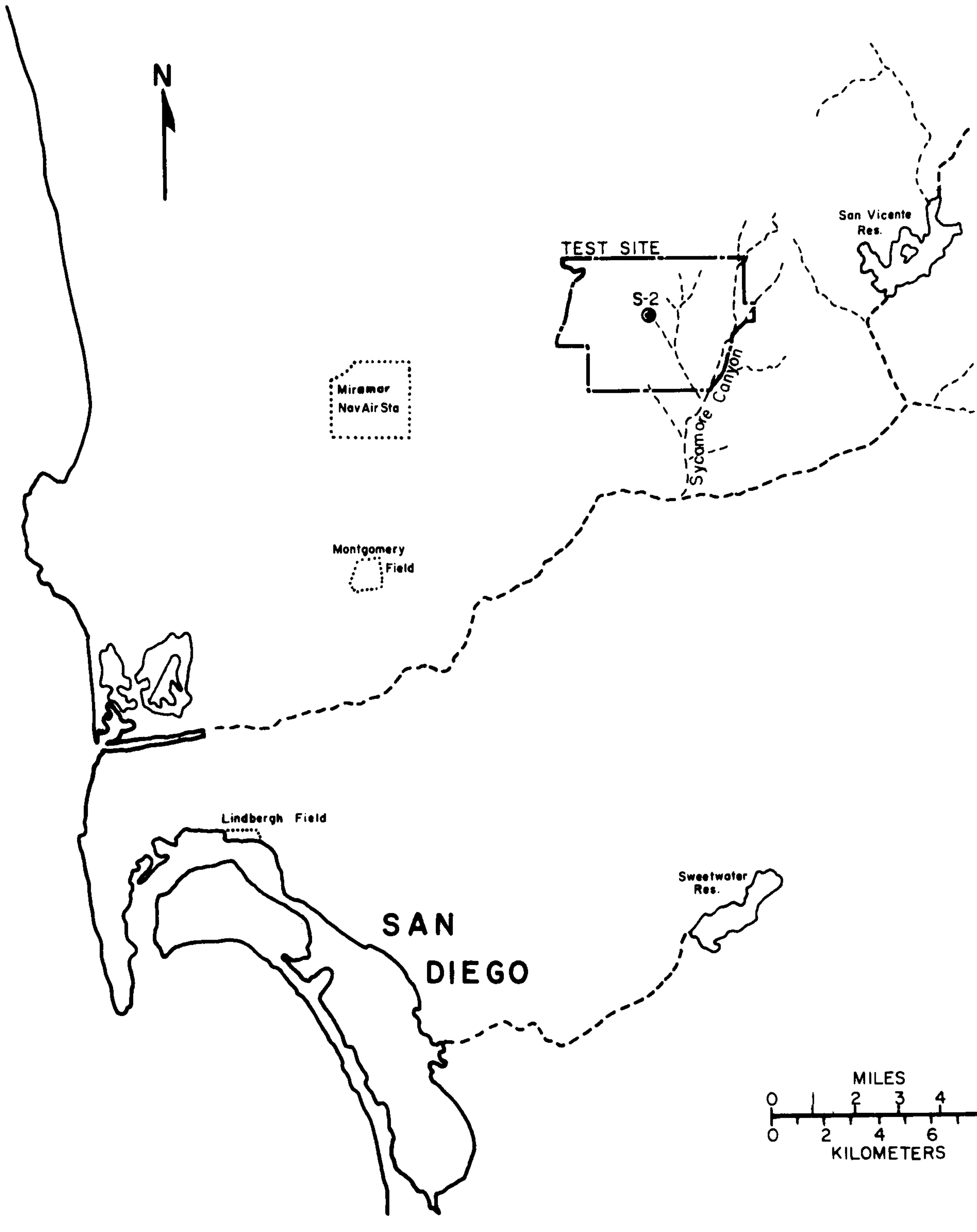


Fig. 3. LOCATION OF SYCAMORE CANYON SITE

may collect in layers below and at the base of the inversion. During the day the mixing is usually sufficient to distribute the material throughout the volume of air beneath the inversion.

2. Large Scale Meteorological Influences

The dominant meteorological feature influencing the circulation along the coast of Southern California is the large North Pacific subtropical anticyclone. In summer, the presence of this high pressure cell, combined with a semipermanent heat low over the desert, is favorable for the development of sea-breeze conditions. These occur with great regularity during the summer months. The sea breeze reaches its strongest proportions during the afternoon as a result of heating of the inland areas and the intensification of the low pressure region. At night, the air cools over the land, the pressure inland rises and, in some cases, the flow may shift to a more easterly direction along the coastal plain. In other cases, the sea-breeze wind may continue in direction but with greatly reduced velocity.

In winter, the position of the North Pacific anticyclone is displaced southward and traveling storms and fronts are occasionally able to move through the Southern California area. The summer thermal low disappears from the desert regions and, in the absence of storm influences, there is more tendency for airflow from the interior toward the ocean. This is particularly true at night but is manifested during the day by a much weaker sea-breeze flow than occurs during the summer. The usual sequence of winds associated with winter storms begins with increasing wind from a southerly direction. As the storm passes eastward, the wind shifts to a north or northwesterly direction.

A moderate temperature inversion is characteristic of the Southern California oceanic and coastal areas. This inversion is produced by subsiding air circulating from the north around the high pressure cell. Its average height is approximately 1500 feet (Neiburger and Edinger, 1954) in the area of interest. The inversion is present most of the time in summer and frequently at other times of the year.

The most pronounced and lowest inversions are produced by air flowing from the interior and being warmed by passage down the coastal slopes. These conditions tend to occur most frequently during the fall months.

3. Winds

The Naval Air Station at Miramar is at an elevation of 475 feet about midway between the Sycamore Canyon site and the coast and 10.5 miles north-northeast from Lindbergh Field (Fig. 3). Its location on a gently sloping mesa leaves the wind observations uninfluenced by local terrain.

An examination of the monthly regime of hourly surface winds for NAS Miramar reveals a remarkably uniform pattern. On the basis of similarity of certain diurnal features the months can be grouped roughly into a summer and winter season with two transitional seasons.

December, January and February show winds characteristic of the cold season. During this time of year the nocturnal land breeze from the east is characteristic of the nighttime hours beginning near midnight and lasting until about two hours after sunrise. Wind speeds are less than nine miles per hour 80 to 90 per cent of the time. The westerly sea breeze does not become well established until afternoon and lasts until about sunset. Wind speeds are higher during the period of the sea breeze, exceeding eight miles per hour about one-half of the time.

July, August and September are quite similar and represent the warm, summer season. The land breeze is often not sufficiently strong to overcome the strong daytime sea-breeze circulation combined with the larger scale flow patterns. The net effect is to produce predominantly calm or very light wind conditions from late evening throughout the night until approximately 0900 PST in the morning. The sea breeze is well established by noon with wind speeds in excess of eight miles per hour from the west or west-northwest until about 1900 PST more than 50 per cent of the time. This flow pattern is repeated with great regularity. Easterly winds are extremely rare during this season.

The other groups of months of the year, March-June and October-November can be considered as transitional warming and cooling periods, respectively.

Winds from a southwesterly direction through northwesterly are favorable for carrying airborne material from the site toward relatively uninhabited areas to the east. Figure 4 summarizes the time of the beginning and end of such wind conditions by month. The period of favorable winds is approximately from noon until 1600 PST during the winter months and from 1000 to 1900 PST during the summer with a greater than 50 per cent frequency of occurrence. During the periods of these westerly winds, speeds are rarely less than four miles per hour, averaging from four to eight miles per hour nearly 50 per cent of the time and greater than eight miles per hour with about the same frequency.

A limited amount of wind data for the various locations at or near the test site has been summarized and is shown in Figs. 5-16. The MRI VectorVanes were operated primarily in support of testing so that the data from these sites are limited to test days.

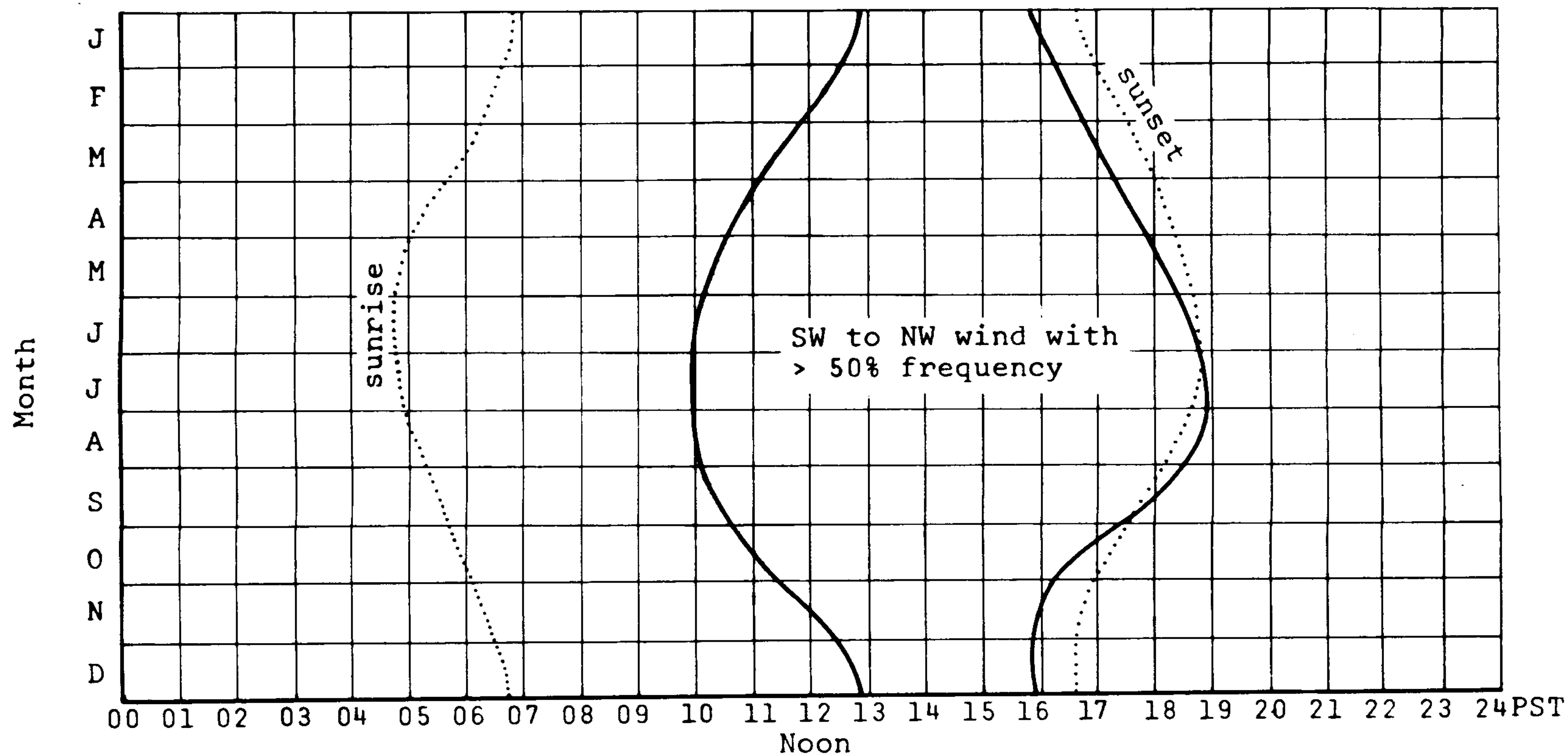


Fig. 4. OCCURRENCE OF SOUTHWEST TO NORTHWEST WINDS AT NAS MIRAMAR

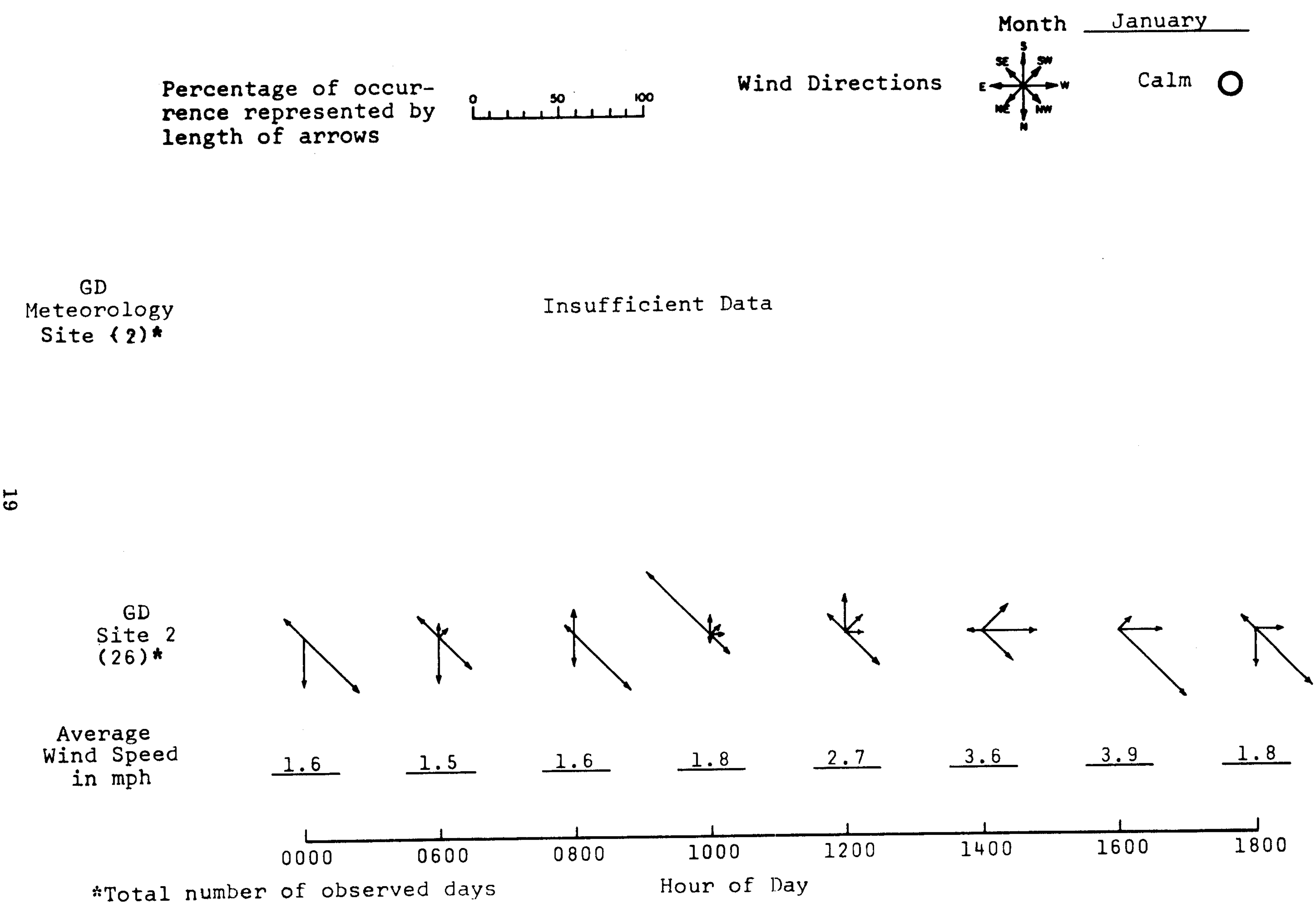
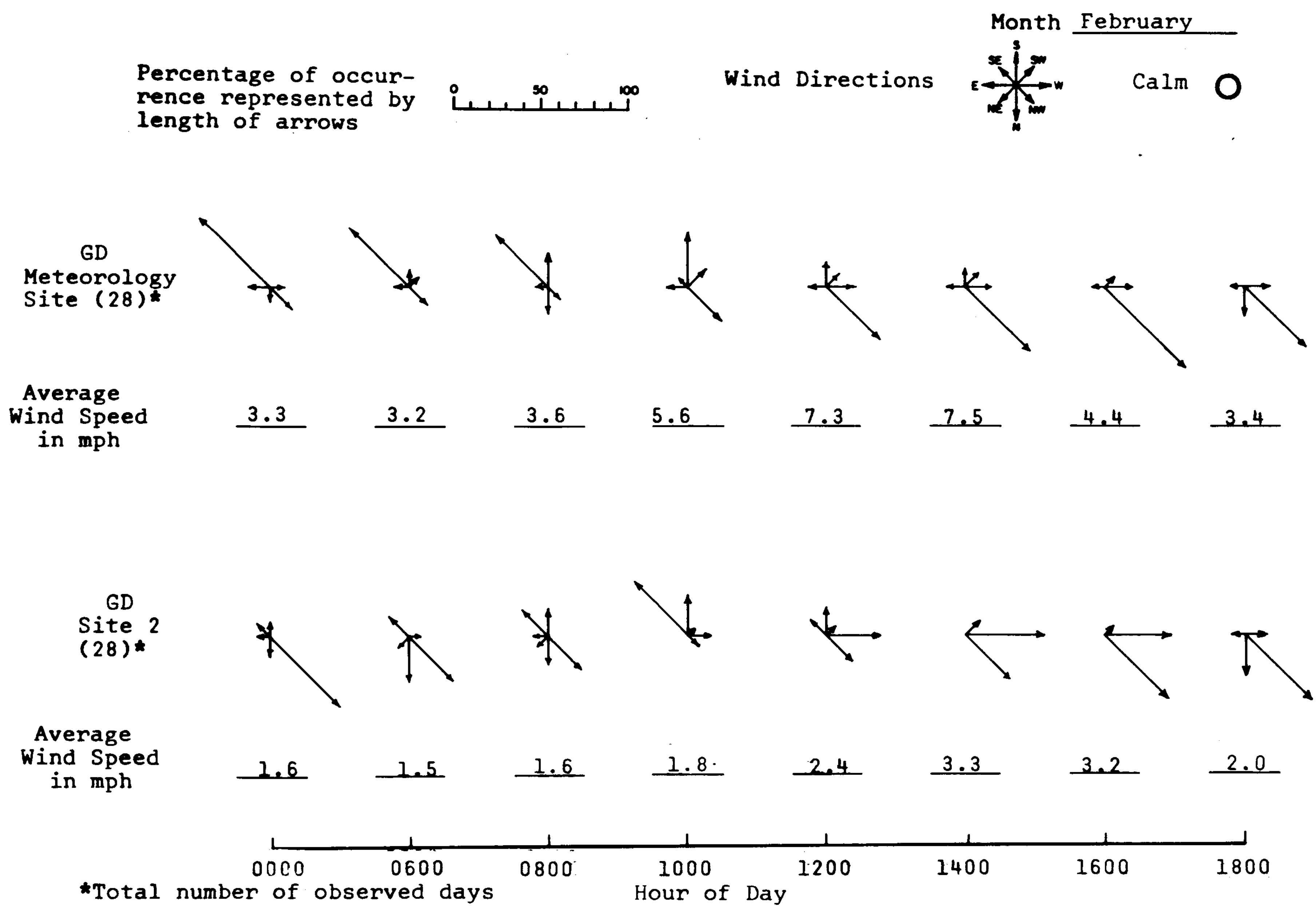


Fig. 5. WIND DISTRIBUTION OVER SYCAMORE CANYON
(frequency of 5% or more shown)



*Total number of observed days

Fig. 6. WIND DISTRIBUTION OVER SYCAMORE CANYON
(frequency of 5% or more shown)

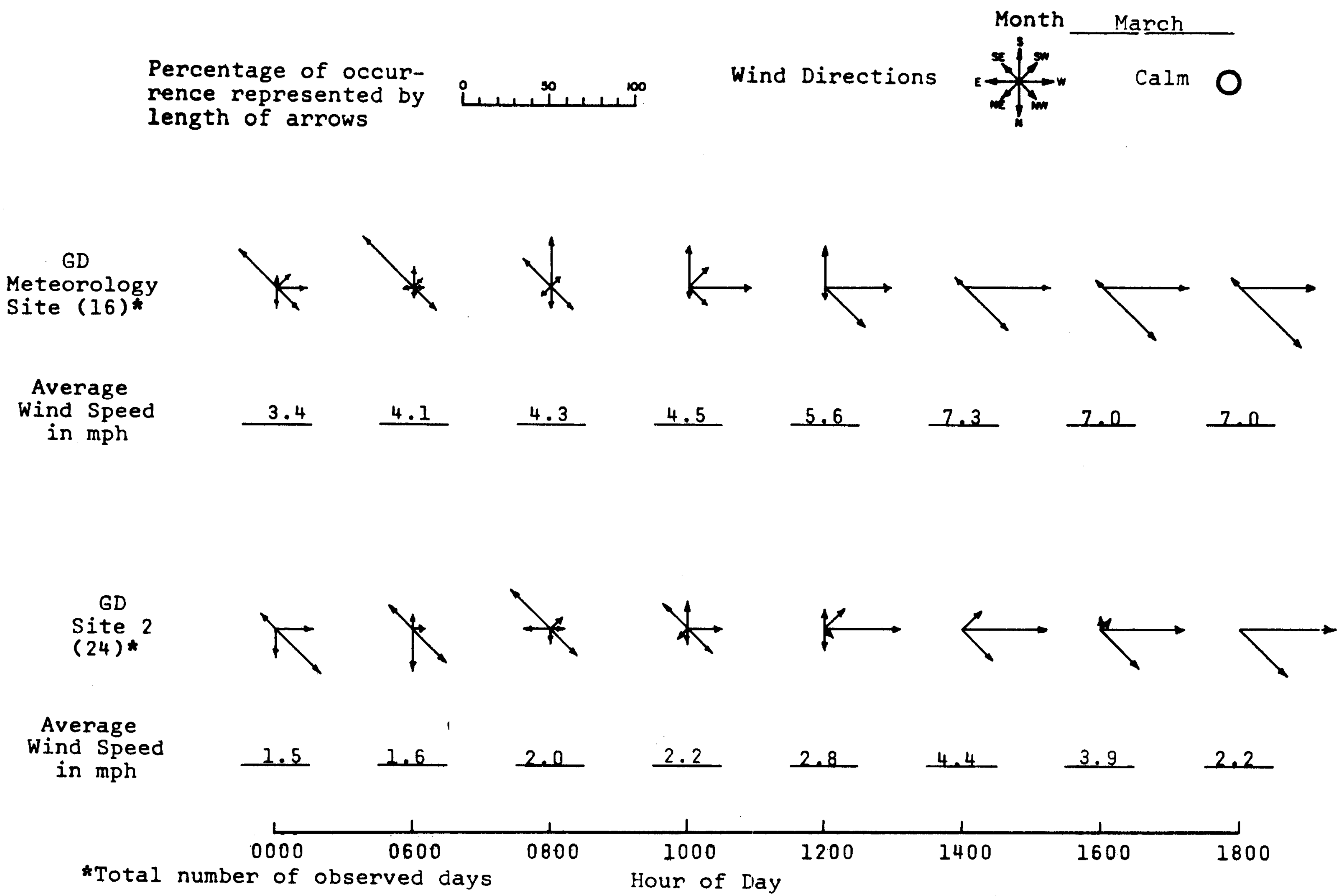


Fig. 7. WIND DISTRIBUTION OVER SYCAMORE CANYON
(frequency of 5% or more shown)

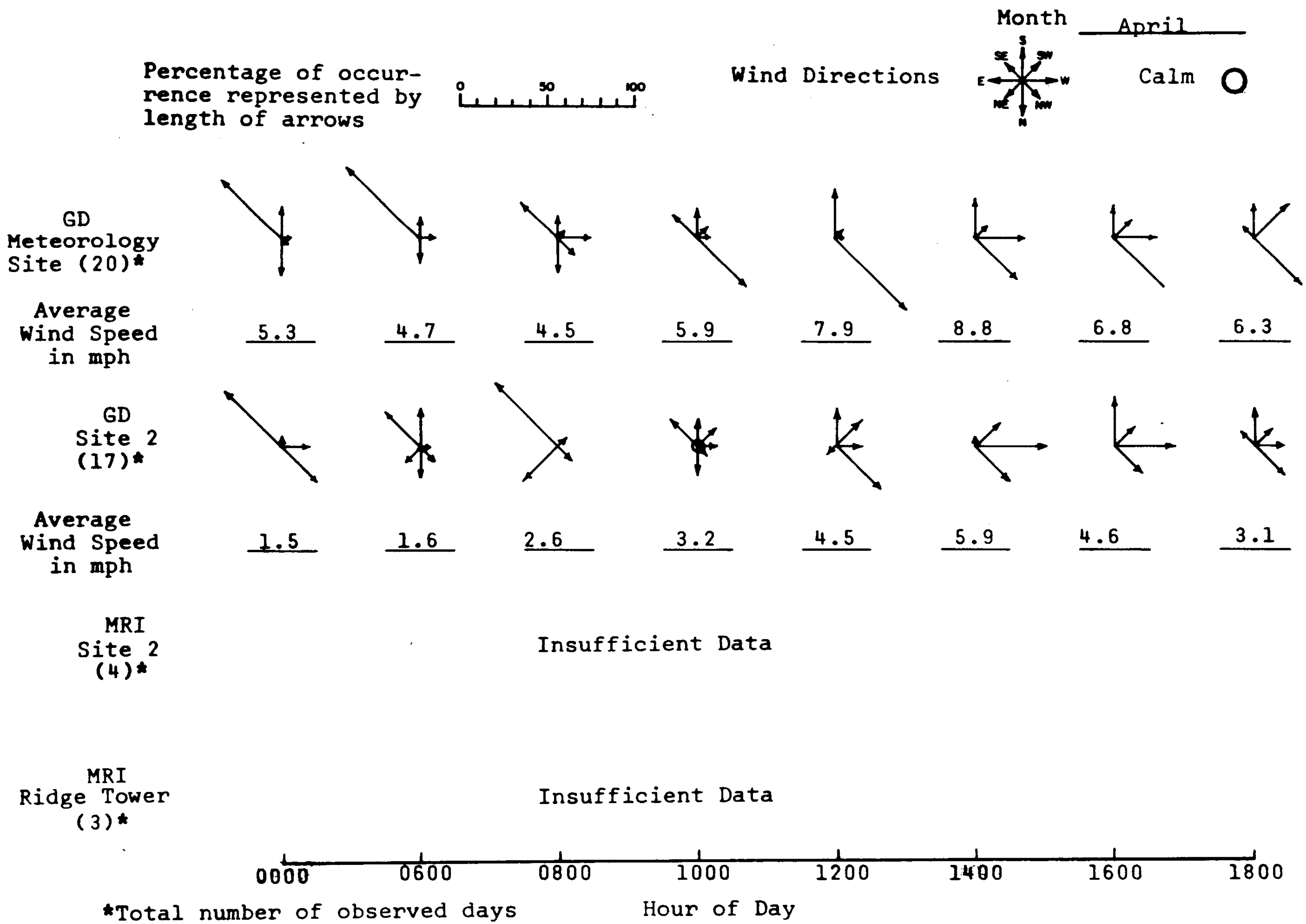


Fig. 8. WIND DISTRIBUTION OVER SYCAMORE CANYON
(frequency of 5% or more shown)

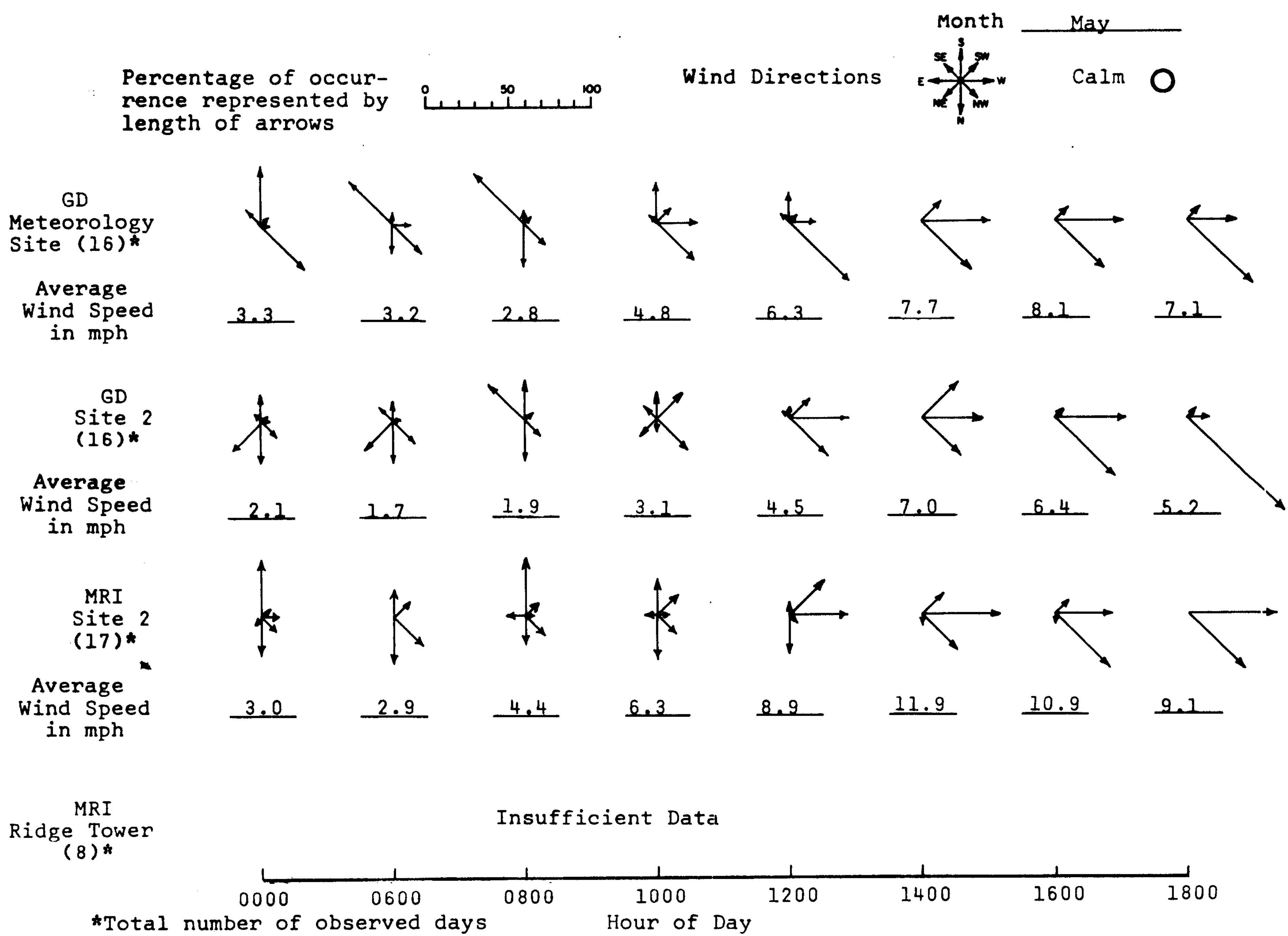
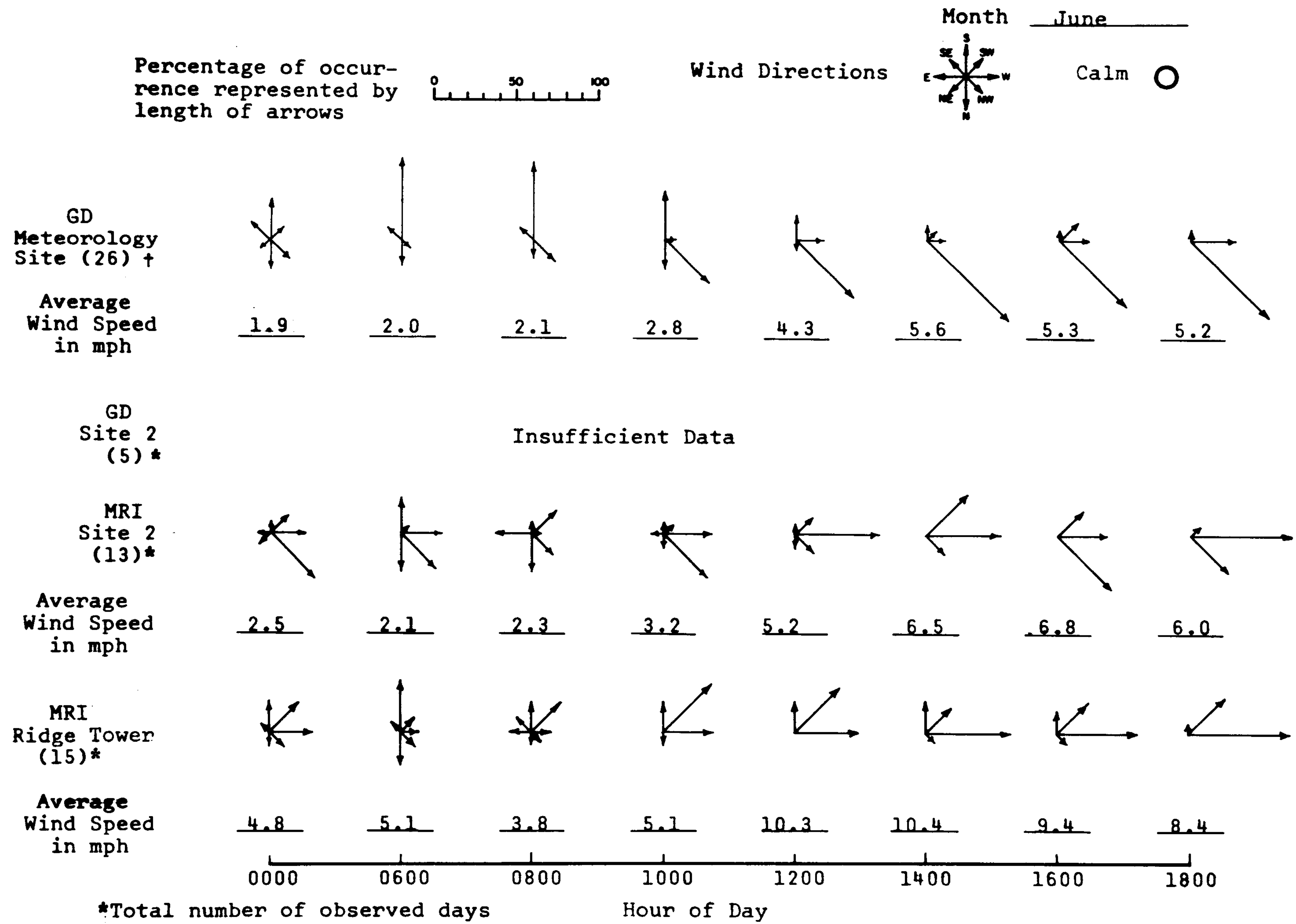
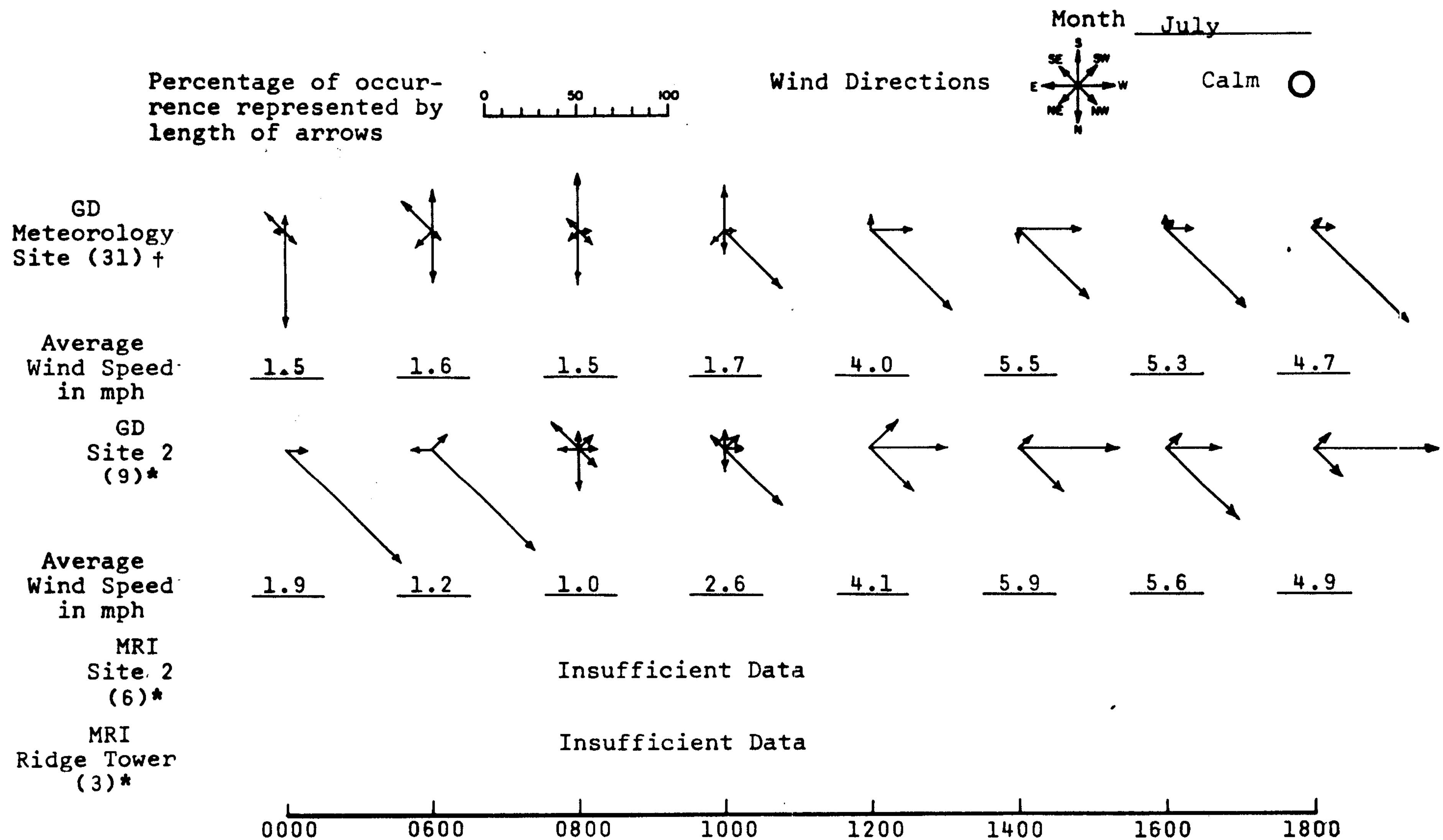


Fig. 9. WIND DISTRIBUTION OVER SYCAMORE CANYON
(frequency of 5% or more shown)



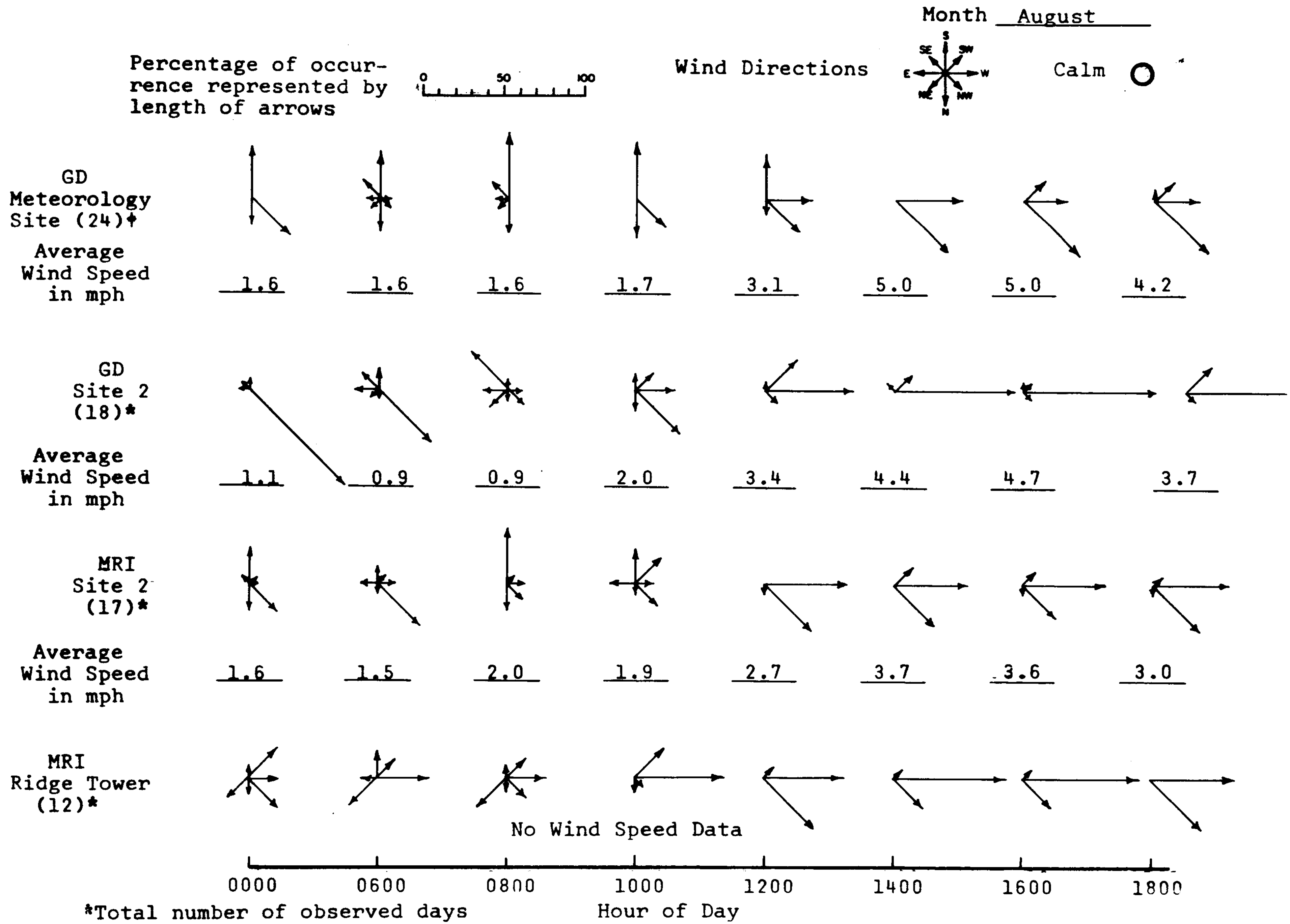
*Total number of observed days
†Based on GD Tech. Memo. 65-061

Fig. 10. WIND DISTRIBUTION OVER SYCAMORE CANYON
(frequency of 5% or more shown)



*Total number of observed days
†Based on GD Tech. Memo. 65-061

Fig. 11. WIND DISTRIBUTION OVER SYCAMORE CANYON
(frequency of 5% or more shown)



*Total number of observed days
†Based on GD Tech. Memo. 65-061

Fig. 12. WIND DISTRIBUTION OVER SYCAMORE CANYON
(frequency of 5% or more shown)

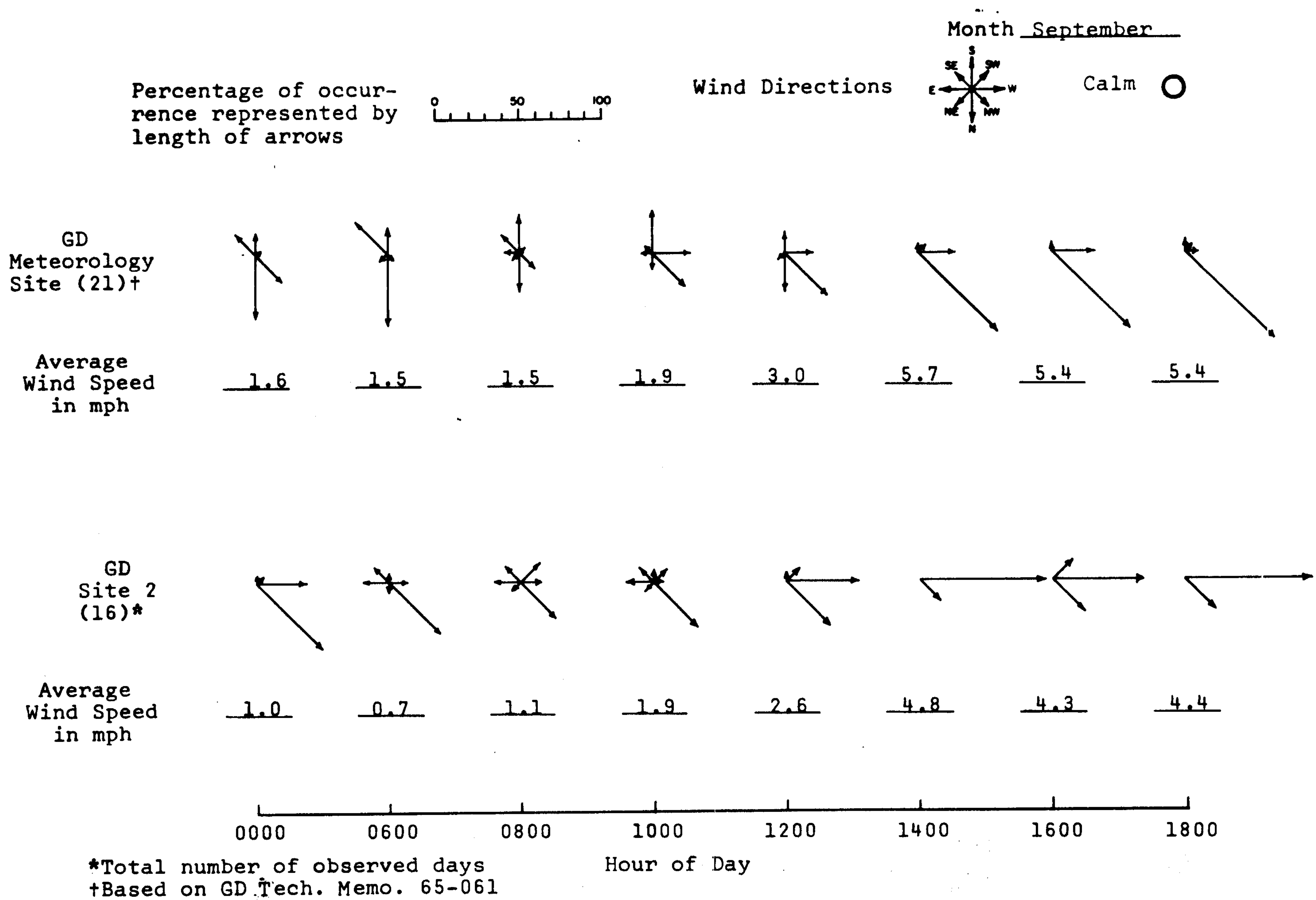


Fig. 13. WIND DISTRIBUTION OVER SYCAMORE CANYON
(frequency of 5% or more shown)

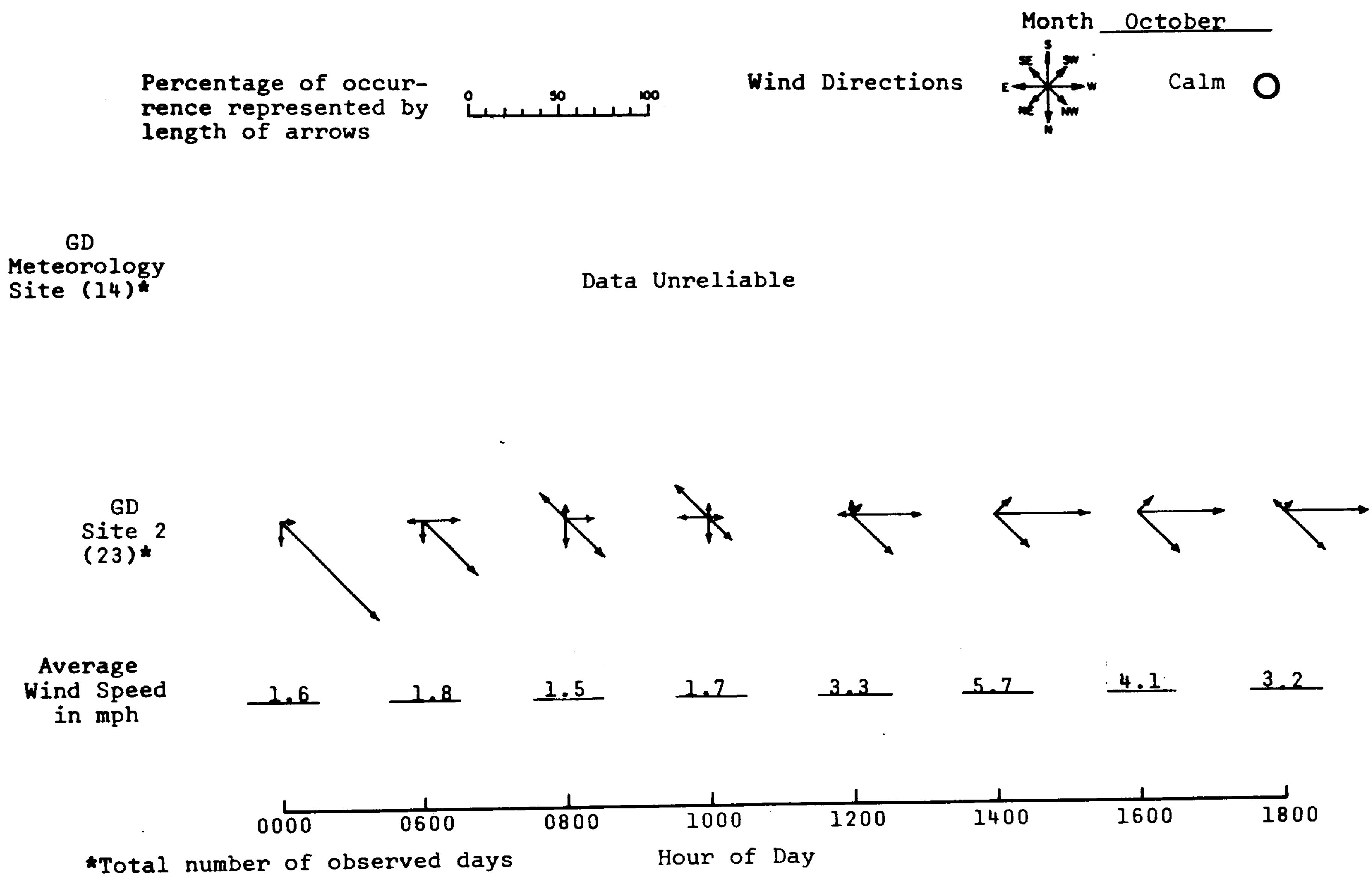


Fig. 14. WIND DISTRIBUTION OVER SYCAMORE CANYON
(frequency of 5% or more shown)

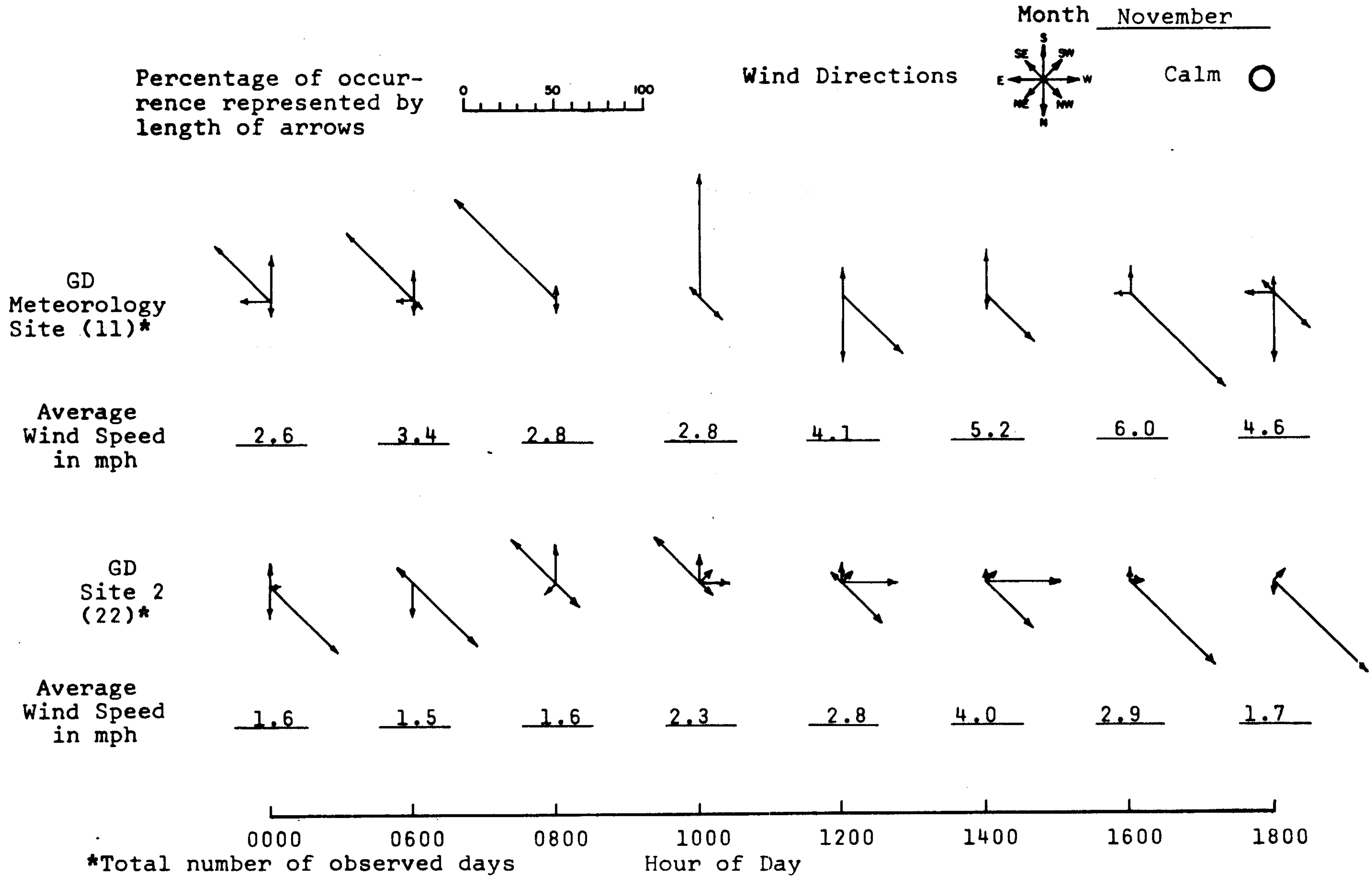


Fig. 15. WIND DISTRIBUTION OVER SYCAMORE CANYON
(frequency of 5% or more shown)

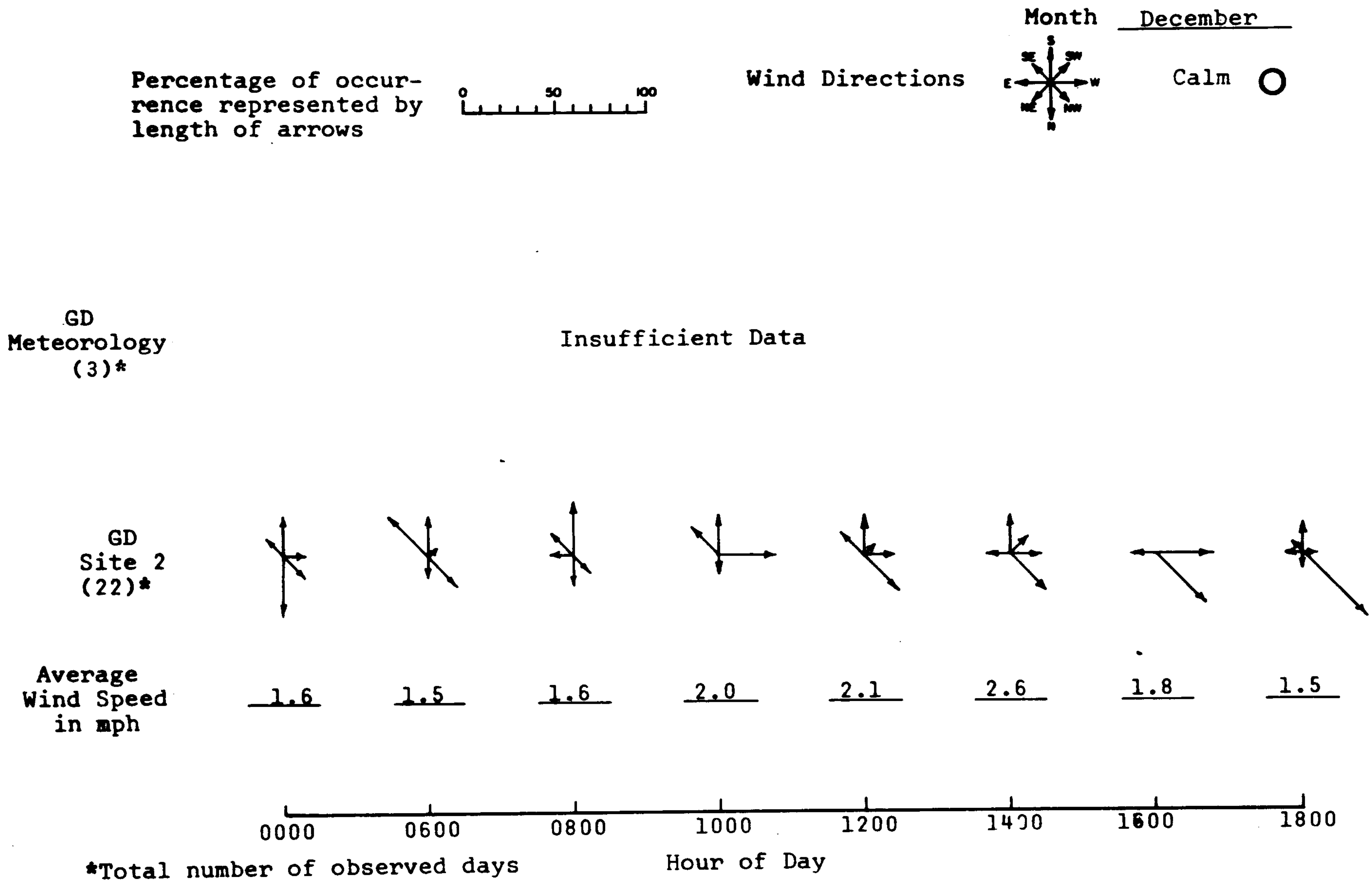


Fig. 16. WIND DISTRIBUTION OVER SYCAMORE CANYON
(frequency of 5% or more shown)

The period of record for the wind sites is inadequate to support a detailed analysis; however, some information can be gained which supports conclusions based on the trajectory data and intuitive considerations. As would be expected, the most predominant and significant feature of the flow, i.e. the sea breeze, can be identified easily at both the Meteorology Site and NAS Miramar. The wind data from the S-2 site located in the Canyon show features, such as up- and down-canyon flow, with varying degrees of distinctness depending on time of day and year and perhaps on other large scale synoptic flow patterns. The occurrence of a significant percentage of both northerly and southerly winds during the night in the spring and early summer months is evident on the summary for NAS Miramar (Holzworth and Blake, 1957) and also shows up in the Canyon stations. The uniform nighttime land breeze is not as evident in Sycamore Canyon as at NAS Miramar. In the warmer months the wind directions at the Meteorology Site show no predominant direction with light wind speeds during the night and morning hours. By noon a westerly sea breeze is established with wind speeds four to eight miles per hour in summer and slightly less in winter. Data available from the other sites show essentially the same afternoon sea-breeze features with a tendency for light nighttime drainage winds during all months.

4. Stability and Temperature Inversions

Upward diffusion of a contaminant is restricted at the inversion base so that, in general, the vertical mixing is confined to the air beneath the inversion. The volume of air available for diluting the contaminant is thus directly related to the height of the inversion base. The amount of energy or upward acceleration required to penetrate or break through an inversion is, of course, related to the "strength" of the inversion. The temperature difference between base and top of the inversion as well as the thickness or difference in height between the top and bottom are commonly used to describe inversion characteristics.

Inversion data from Montgomery Field should be quite representative of conditions over the test site and are presented in Figs. 17-22 (Holzworth and Bell, 1963). Montgomery Field is located on the open mesa about nine miles southwest of Sycamore Canyon at an elevation of 407 feet. The frequency of occurrence of inversions for the various height categories shows a decidedly greater diurnal range during winter than in summer. Except for a greater incidence of surface inversions at night than in the afternoon, there is little diurnal variation during July, August and September with only minor differences in June and October. During the other months of the year there is a much greater frequency of occurrence of low-level inversions at 0400 PST than at 1600 PST, the primary night-time height being at the surface.

The annual trend of afternoon inversions below 2500 feet MSL shows a low frequency during fall, winter and spring with a maximum during July, August and September, the increase being due to inversions above the surface. The large diurnal change in frequency of low-level inversions during the winter can be attributed to the fact that the inversions are of the radiation type and shallow so that they are more frequently removed by daytime heating. Figures 17 and 18 show a marked decrease from night to day of the frequency of inversions of all thickness categories during the winter. During the summer the frequency of inversion thickness categories shows little diurnal change as was evidenced in the graphs of height frequency.

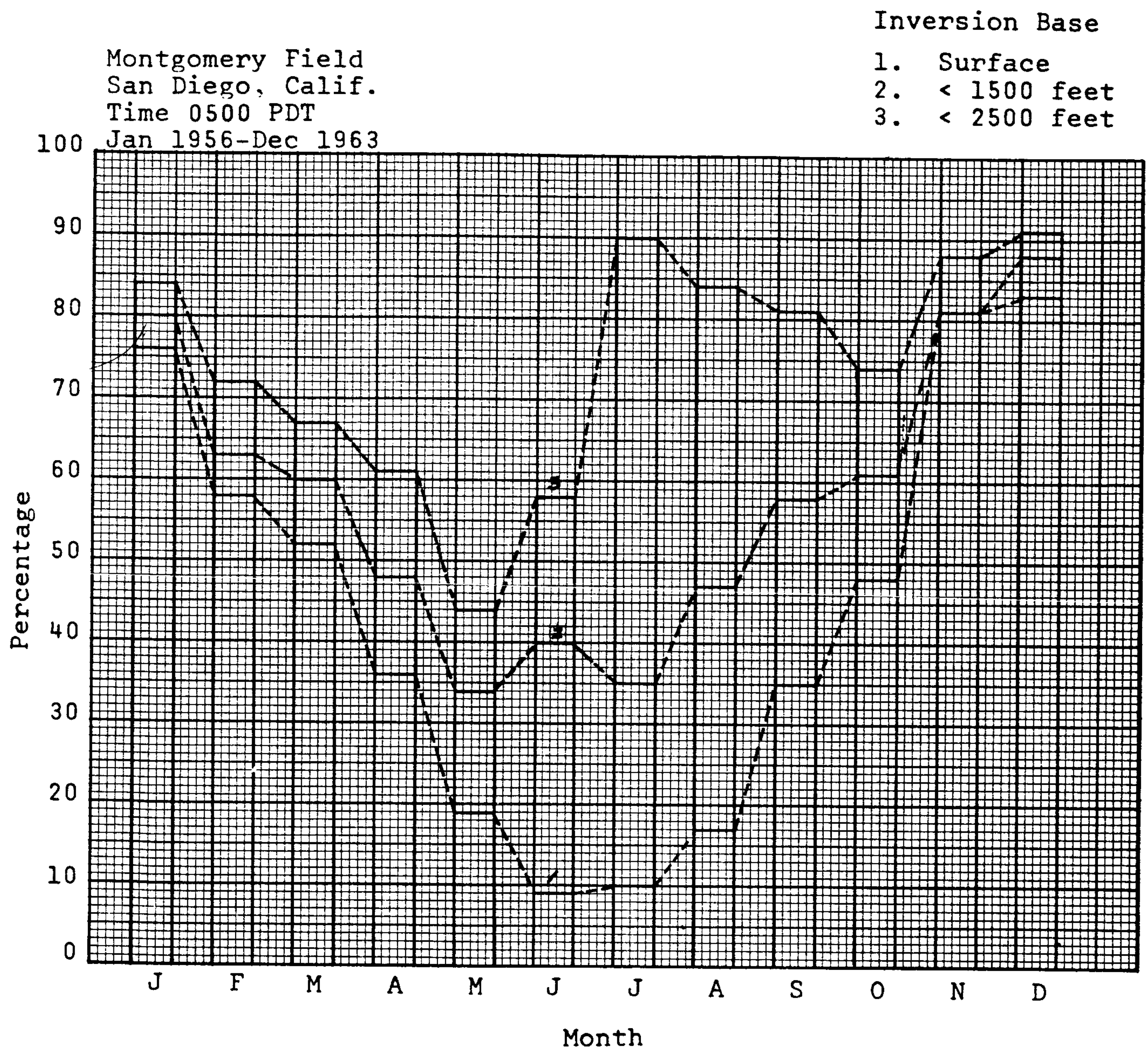


Fig. 17. PERCENTAGE FREQUENCY OF OCCURRENCE OF HEIGHT OF INVERSION BASE (FEET MSL)

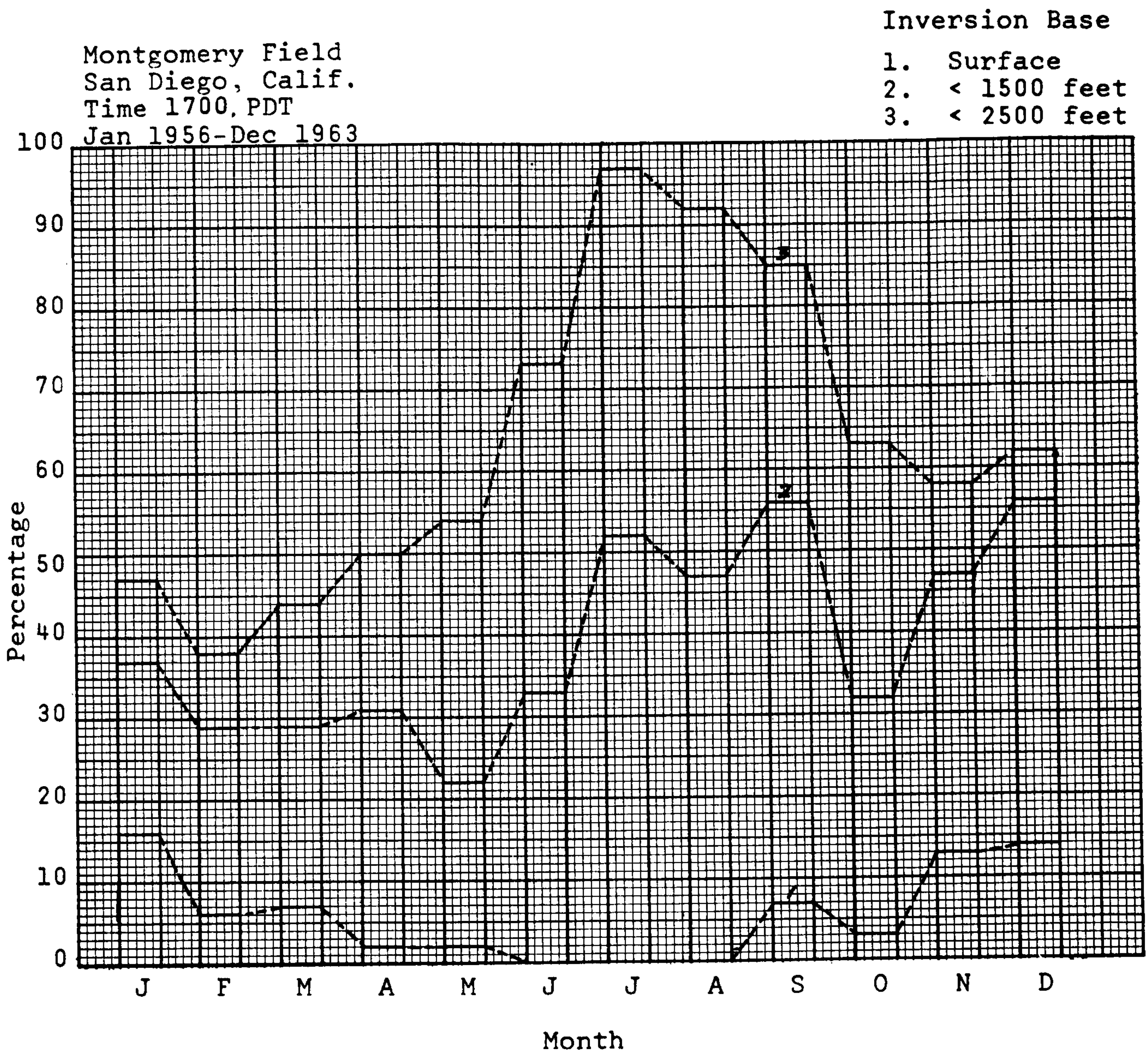


Fig. 18. PERCENTAGE FREQUENCY OF OCCURRENCE OF HEIGHT OF INVERSION BASE (FEET MSL)

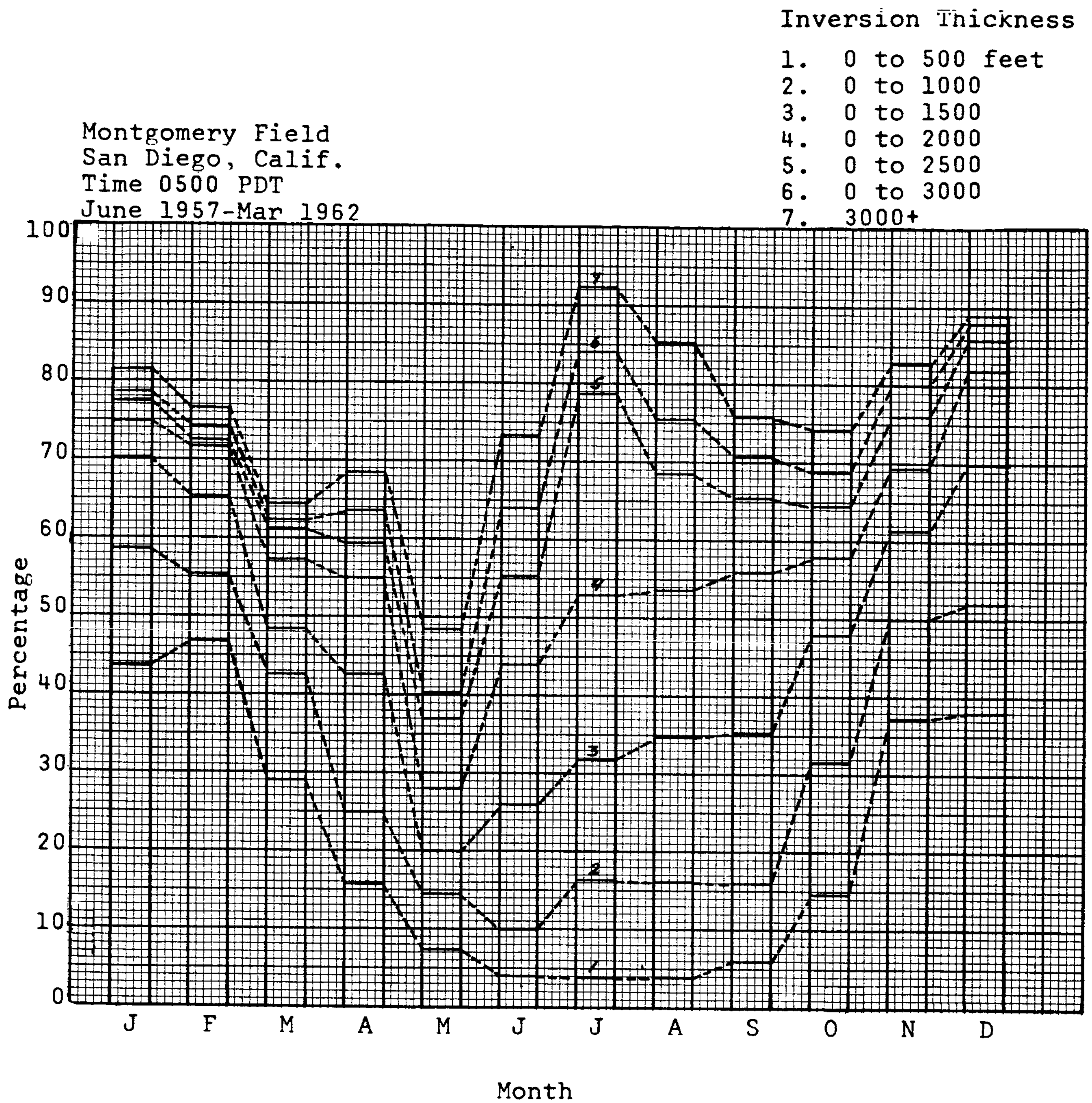


Fig. 19. PERCENTAGE FREQUENCY OF OCCURRENCE OF THICKNESS OF INVERSION (FEET) FOR BASES AT OR BELOW 2500 FEET MSL

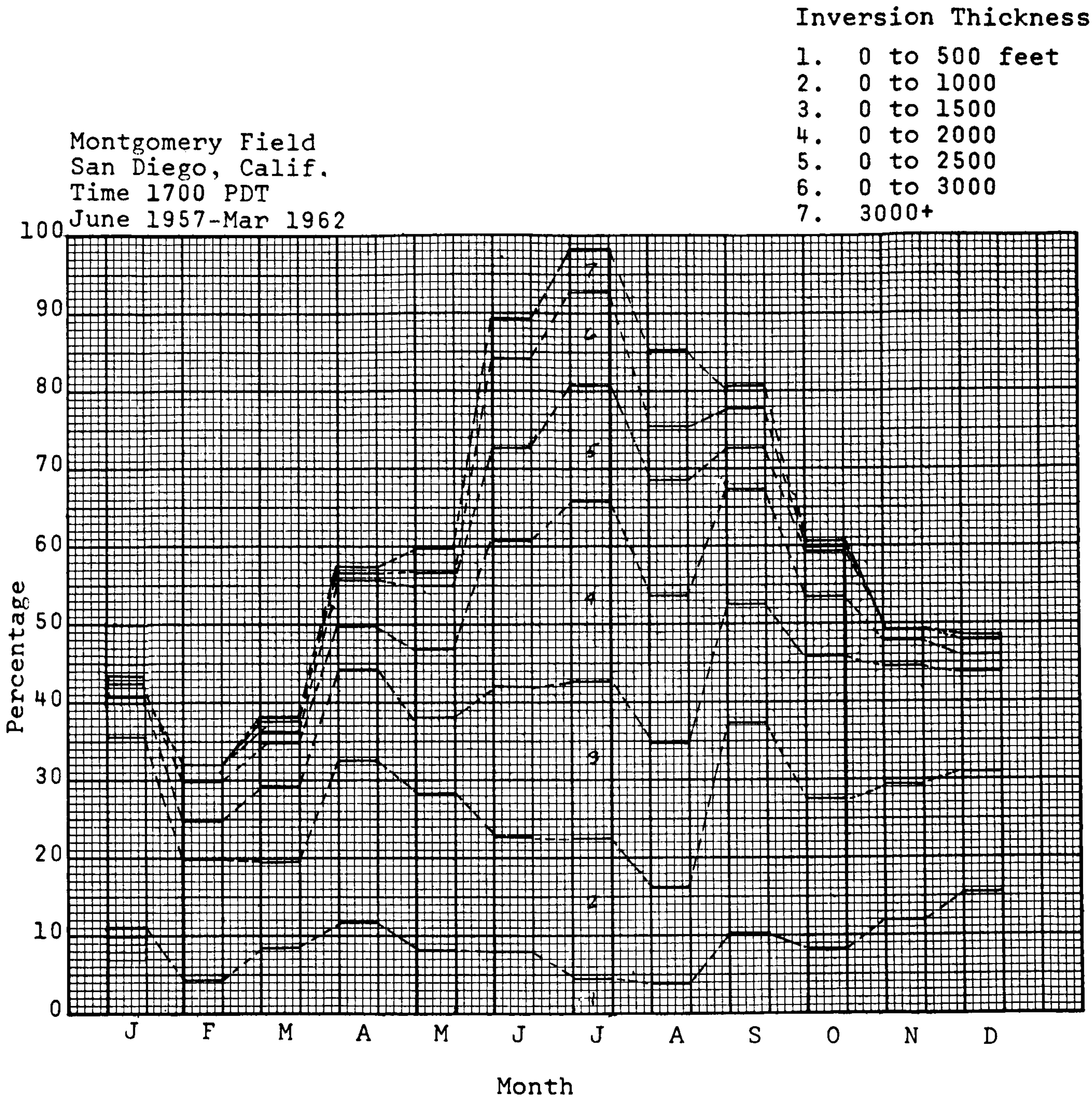


Fig. 20. PERCENTAGE FREQUENCY OF OCCURRENCE OF THICKNESS OF INVERSION (FEET) FOR BASES AT OR BELOW 2500 FEET MSL

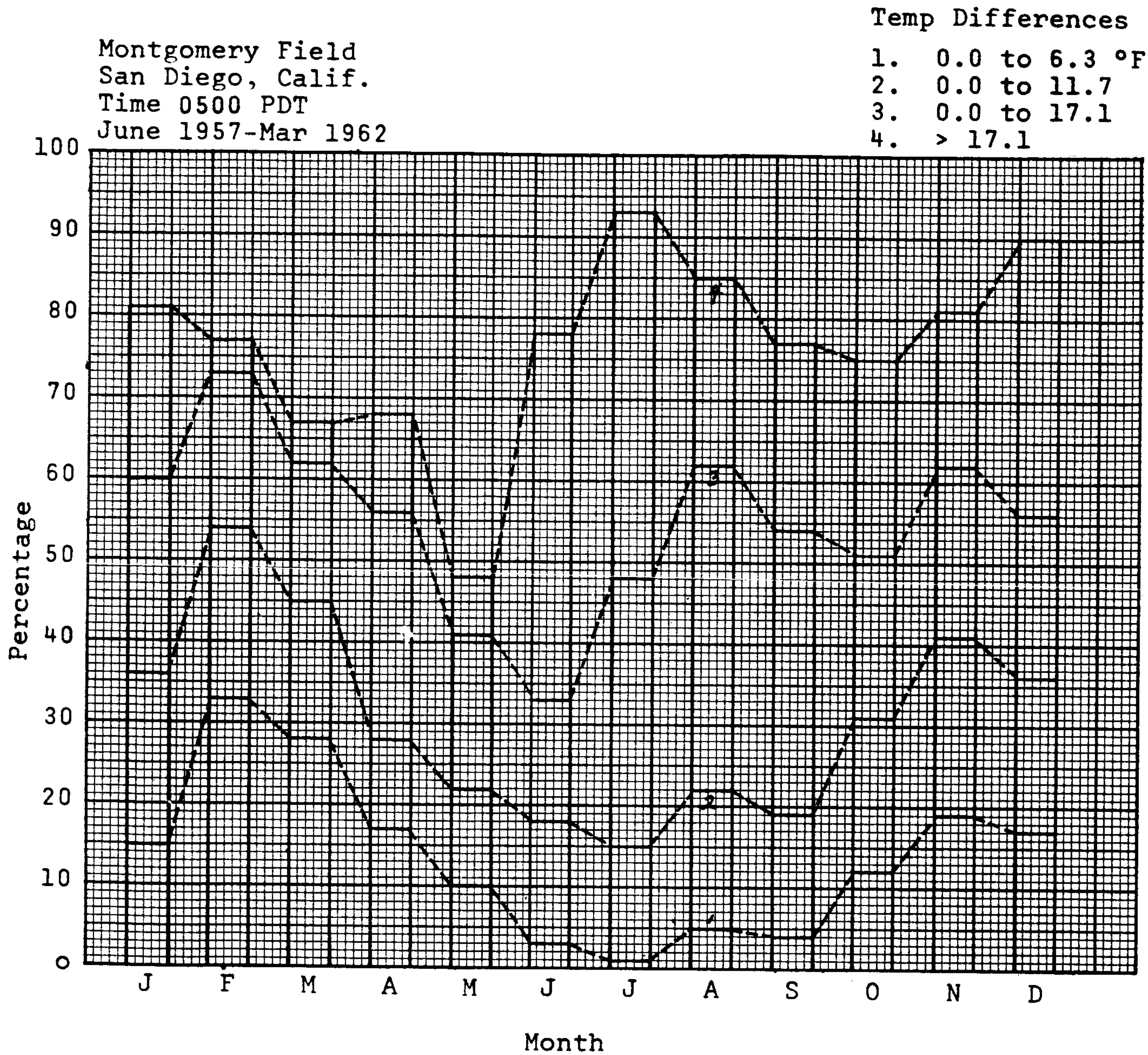


Fig. 21. PERCENTAGE FREQUENCY OF OCCURRENCE OF TEMPERATURE DIFFERENCE (°F) OF INVERSIONS (TOP MINUS BASE) FOR BASES AT OR BELOW 2500 FEET MSL

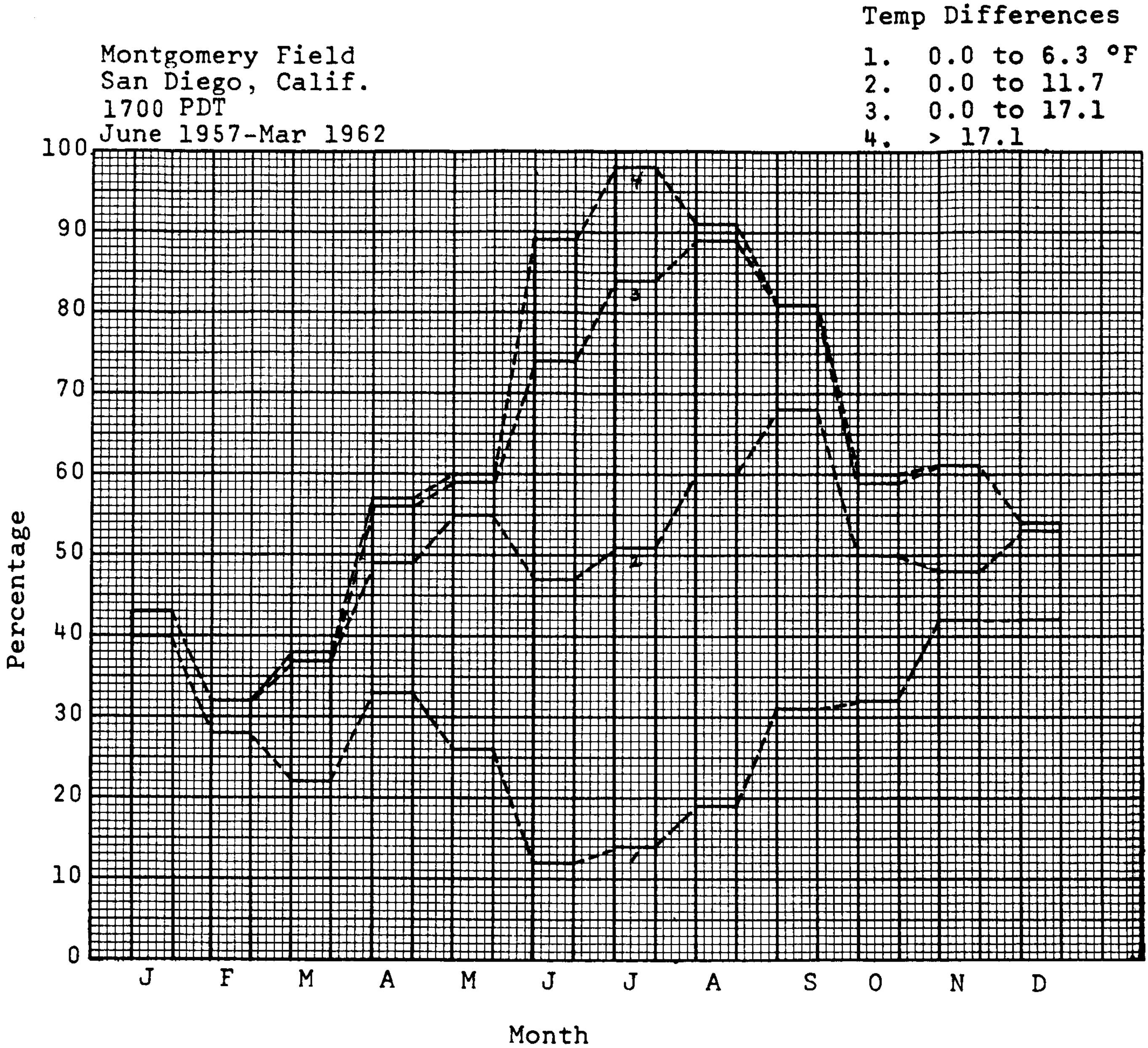


Fig. 22. PERCENTAGE FREQUENCY OF OCCURRENCE OF TEMPERATURE DIFFERENCE (°F) OF INVERSIONS (TOP MINUS BASE) FOR BASES AT OR BELOW 2500 FEET MSL

In summary, afternoon inversions below 2500 feet occur with less frequency in the cooler months but with a maximum frequency in summer. The frequency of inversions between 1500 and 3000 feet in thickness with bases below 2500 feet MSL shows a similar minimum during the winter months with a maximum during the summer. The frequency of inversions up to 1500 feet thick shows no significant seasonal changes. The frequency of occurrence of both height and thickness categories shows a pronounced diurnal variation during the cooler months with little change during July, August and September.

C. Diffusion Model

The classical model of diffusion from a point source on the ground can be written as (Pasquill, 1962):

$$D(x,y,z) = \frac{Q}{\pi \bar{u} \sigma_y \sigma_z} e^{-\frac{y^2}{2\sigma_y{}^2} - \frac{z^2}{2\sigma_z{}^2}} \qquad (1)$$

where D is the total dosage received at a downwind location, Q is the source strength in terms of total material released, $\bar{u}$ is the mean wind velocity, σ_y and σ_z are the cloud dimensions at the sampling point (x,y,z). For the case of maximum crosswind dosage at a distance x from the source Eq. (1) reduces to:

$$D_{max}(x,o,o) = \frac{0.318Q}{\bar{u}\sigma_y\sigma_z} \; . \qquad (2)$$

Adaptation of Eq. (1) to the ground dosage from an elevated point source requires only the substitution of H (release height) for z:

$$D(x,o,H) = \frac{Q}{\pi \bar{u} \sigma_y \sigma_z} e^{\frac{-H^2}{2\sigma_z{}^2}} \; . \qquad (3)$$

There have been several proposed techniques for determining σ_y and σ_z, the parameters which describe the rate of spreading of the cloud as it moves downwind.

Smith and Hay (1961) have developed an approximate rate of cloud growth which can be directly related to environment turbulence by the following expression:

$$\frac{d\sigma}{dx} = 3i^2$$

where σ refers to the cloud size and i is a measure of the turbulence which includes all effective eddy sizes. In practice, i has been taken by MRI to be the standard deviation of a fast-response wind vane fluctuation over an interval of 30 seconds (σ_{30}). This relation was found to express the cloud rate of growth for observational data at Point Arguello (Smith, Kauper, Berman and Vukovich, 1964). There is, in general, a direct correlation between σ_y and σ_z. Environment conditions which lead to large horizontal spreading rates also result in rapid vertical spreading rates. Previous experience has shown that a rough, average relation between the two is $\sigma_y = 1.5\sigma_z$ where the factor 1.5 should be decreased for unstable environment conditions and increased for stable temperature environments. The values of σ_{30} for the Sycamore Canyon tests have been obtained from turbulence records taken near the top of the S-2 tower.

Slade (1965) has summarized available experimental data on quasi-instantaneous point source releases and suggests the following values for σ_y and σ_z:

DISPERSION ESTIMATES (FROM SLADE, 1965)

Downwind Distance

σ_y (in m)	100 m	4000 m
Unstable	10.0	300
Neutral	4.0	120
Very unstable	1.3	35
σ_z (in m)		
Unstable	15.0	220
Neutral	3.8	50
Very unstable	0.75	7

The above techniques yield estimates of σ_y and σ_z which can be used in Eqs. (1) and (3) to obtain estimates of ground dosage downwind from the release. The technique suggested in the WIND equation (Haugen and Taylor, 1963) goes directly to an estimate of the peak crosswind dosage [analogous to Eq. (2)] through the following equation:

$$\frac{D_{max}}{Q} = 0.00211 \times {}^{1.96}\sigma(\theta)^{-\ 0.506}(\Delta T+10)^{4.33} \qquad (4)$$

where $\sigma(\theta)$ is the standard deviation of horizontal turbulence fluctuations near the source (in degrees) and ΔT is the temperature difference between six and 54 feet (in °F). Observational data for $\sigma(\theta)$ and ΔT are available for the Sycamore Canyon tests from the S-2 tower although ΔT was measured over a 75-foot interval from 63 to 138 feet above the ignition pad. Measurement of ΔT at these higher levels tends to emphasize the environment conditions in which the cloud spends most of its time rather than the very local conditions at lower levels around the base of the tower.

Meteorological parameters required for the various diffusion models and derived from the observational data are given in the following table:

TABLE II
METEOROLOGICAL PARAMETERS
(Measured at the top of the S-2 Tower)

Trial Number	$\bar{u}$ (mph)	ΔT (F°)	σ_θ (°)	σ_ϕ (°)	Wind Direction
1	3.6	-1.3	11.0	6.5	WNW
2	5.4	-2.3	14.5	8.1	WNW
3	3.8	-0.9	14.1	8.8	WNW
4	9.7	-0.9	11.8	5.2	WNW
5	6.1	-2.2	14.2	8.5	WSW
6	5.9	-2.2	16.8	6.5	WNW
7	6.6	-1.3	20.4	6.5	W
8	8.4	-1.8	13.9*	9.3	SW
9	8.6	-1.8	19.2*	12.8	WSW
10	3.2	-0.4	14.7*	9.8	WNW
11	8.4	-1.1	14.7*	9.8	WSW
12	3.8	-0.9	12.3*	8.2	W
13	7.0	-1.1	7.8*	5.2	WNW
14	8.6	-1.1	8.7*	5.8	NW
15	6.6	-0.9	17.6	8.0	SSW
19	7.5	-0.7	19.5	7.1	WSW
20	5.9	-0.9	10.3	8.6	WSW
21	7.5	-0.9	17.7	7.5	W
22	8.4	-0.5	10.0*	6.7	WNW
23	4.1	----	13.0*	8.7	NNW
24	6.8	----	10.5*	7.0	WNW
25	8.4	-0.9	10.2*	6.8	WSW
26	7.7	0.0	6.7*	4.5	NNW
27	2.5	-1.3	16.5	6.0	W
28	4.1	+0.3	16.8	6.5	WNW
29	8.6	----	11.8	7.6	SW
31	6.5	Missing	----	---	WSW

σ_θ and σ_ϕ represent standard deviations of horizontal and vertical turbulence.

$\Delta T+$ means increase of temperature with height.

* Estimated from chart records.

The temperature differences in Table II can be compared to an expected difference of about 0.7F° with a neutral lapse rate for the height difference of 75 feet. The trials were therefore conducted primarily in unstable conditions with only occasional trials in a neutral or stable environment.

V. TEST RESULTS

A. FP Tracer Results

Dosage maps for each of the trials are shown in the Appendix. Also shown on the maps are the visual cloud trajectories obtained from photographs of smoke made by General Dynamics/Convair ground cameras and from slides made in the orbiting aircraft. Examples of the aircraft photographs are shown in Fig. 23. In all cases, the trajectory represents the combined data from both sources carried as far as the smoke remained visible.

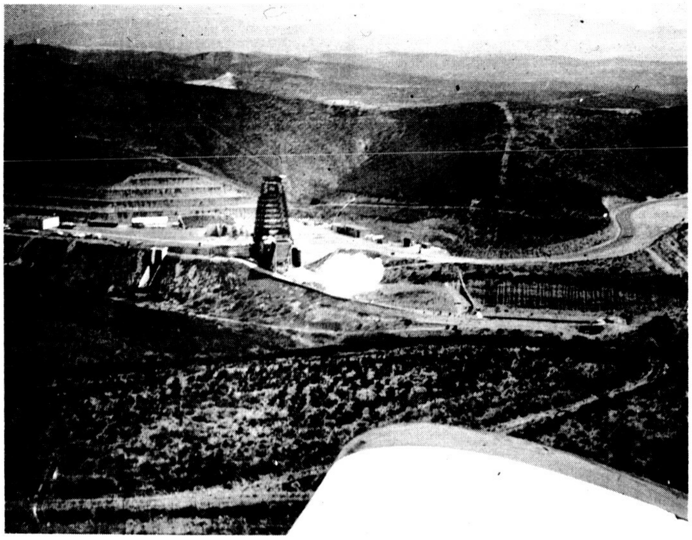
Dosages plotted on the trial maps in the Appendix have been adjusted to a common source strength of 100 pounds of F_2 and are given in ppm-minute by volume. The use of 100 pounds of F_2 is merely a convenient reference standard and does not indicate that these plotted dosages of F_2 were actually observed. The FP dosages might also have been adjusted to a common release of 100 pounds of HF. In this case, the values shown on the maps should be divided by 0.526.

Twenty-three of the FP tracer trials may be used to characterize the diffusion environment of the Sycamore Canyon area. These include all cold source trials and those releases made shortly before or after the hot source trials which served as a control on the behavior of the hot clouds. The most appropriate point of reference is the maximum dosage on each of the three crosswind sampling lines. Comparisons have been made of these values with dosages estimated from model calculations. FP dosages have been converted to equivalent 100-pound releases of F_2 in a manner described in the Appendix.

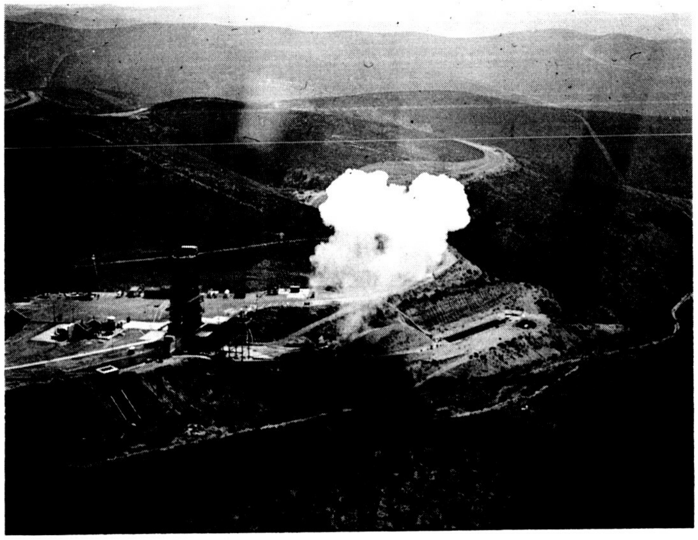
Figure 24 shows a comparison of observed maximum dosages with those calculated from the WIND equation. This equation applies to 30-minute releases and to flat terrain. Hence, it should not be expected to fit the dosage patterns observed for instantaneous sources and rough terrain.

Figure 24 shows that all observed dosages were near or below those calculated from the WIND equation. As shown in

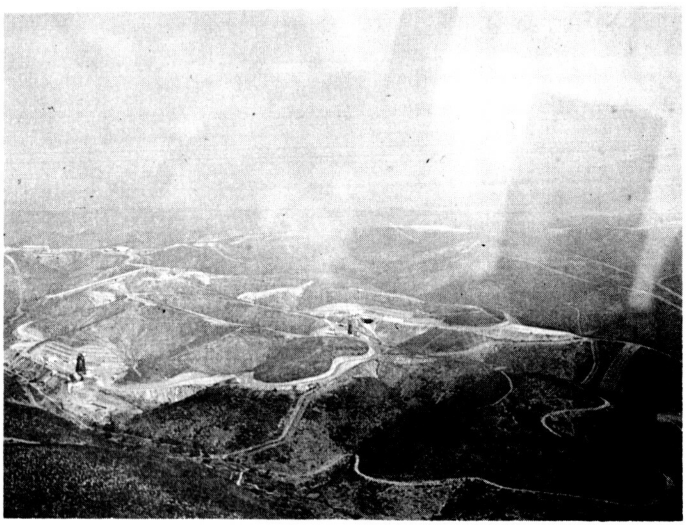
Trial 26, 9 August 1965



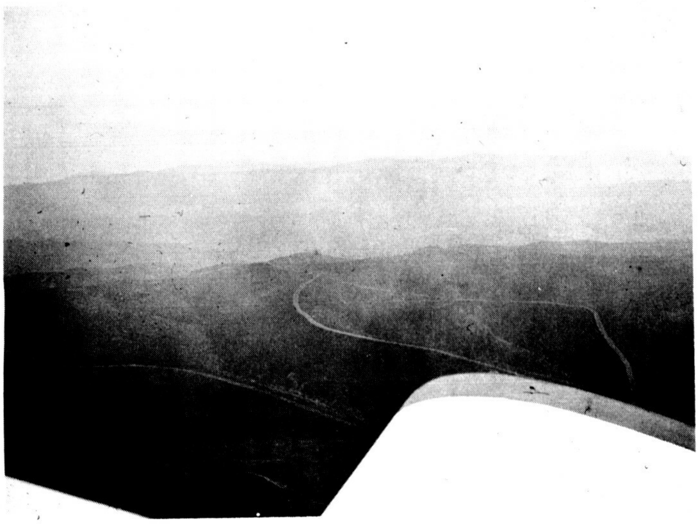
Ignition Time



Ignition Time + 15 Seconds



Ignition Time + 90 Seconds



Ignition Time + 135 Seconds

Fig. 23. SMOKE PHOTOGRAPHS FROM AIRCRAFT

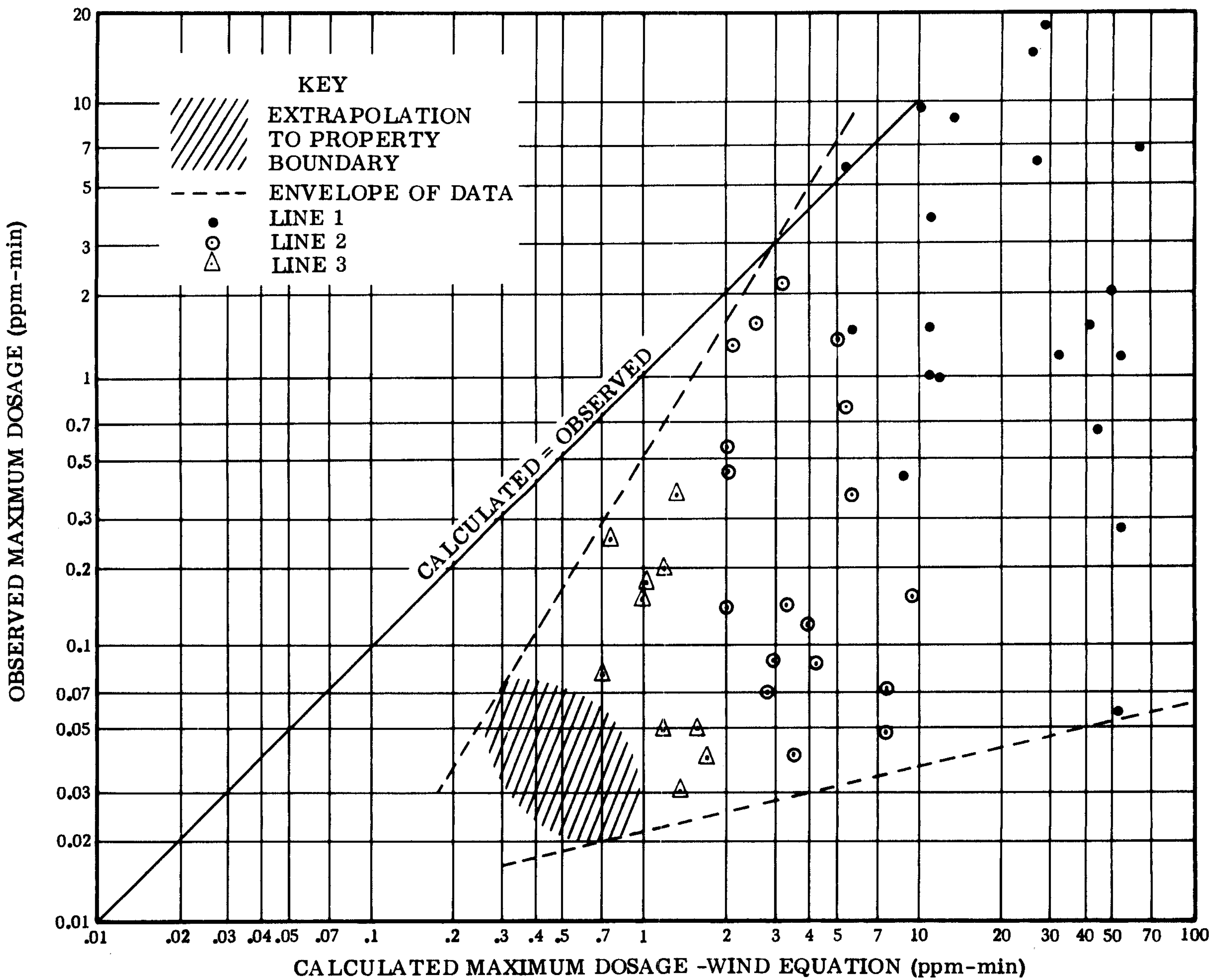


Fig. 24. COMPARISON OF OBSERVED DOSAGES AND WIND CALCULATION

the figure, greatest variability occurs on Line 1, near the release. Occasionally, the observed values approach the WIND dosages but, at times, show very much lower values. Maximum dosages for Lines 2 and 3 also show lower observed values but with decreased variability as indicated by the envelope suggested by the dashed lines. The shaded area represents an extrapolation from Line 3 to the boundary of the Sycamore Canyon property and is based on a $1/x^2$ decrease in dosage with distance.

A similar graph (not shown) has been drawn for maximum dosages calculated from the $(3i^2)$ diffusion model. The deviations between observed and calculated dosages are nearly identical with those shown in Fig. 24 and the data suggest that no improvement would be made by using a diffusion model more appropriate to an instantaneous source.

It is apparent from Fig. 24 that the maximum dosage data stratify according to distance, i.e. Line 1, 2 and 3 values group together on the graph. This suggests that distance is the primary influence in determining observed dosages. A regression analysis of the Line 1 and Line 3 data versus distance showed a correlation coefficient of 0.53. Additional correlation studies for Line 1 and Line 3 individually did not indicate that the meteorological parameters would contribute substantially to the ability to estimate observed dosage. Correlation coefficients for wind speed, ΔT and turbulence versus dosage generally ranged from 0.10 to 0.30. A similar conclusion was reached by Taylor (1965) in an analysis of Project Sand Storm wherein the small-scale effects of hot sources and unstable conditions caused sufficient variability so that distance remained as the primary dosage estimating factor.

Figure 25 shows the maximum observed dosages from Fig. 24 plotted as a function of distance. When the median values for the Line 1 data and for the Line 3 data are connected, the line labeled "50%" results. Also shown are similar lines

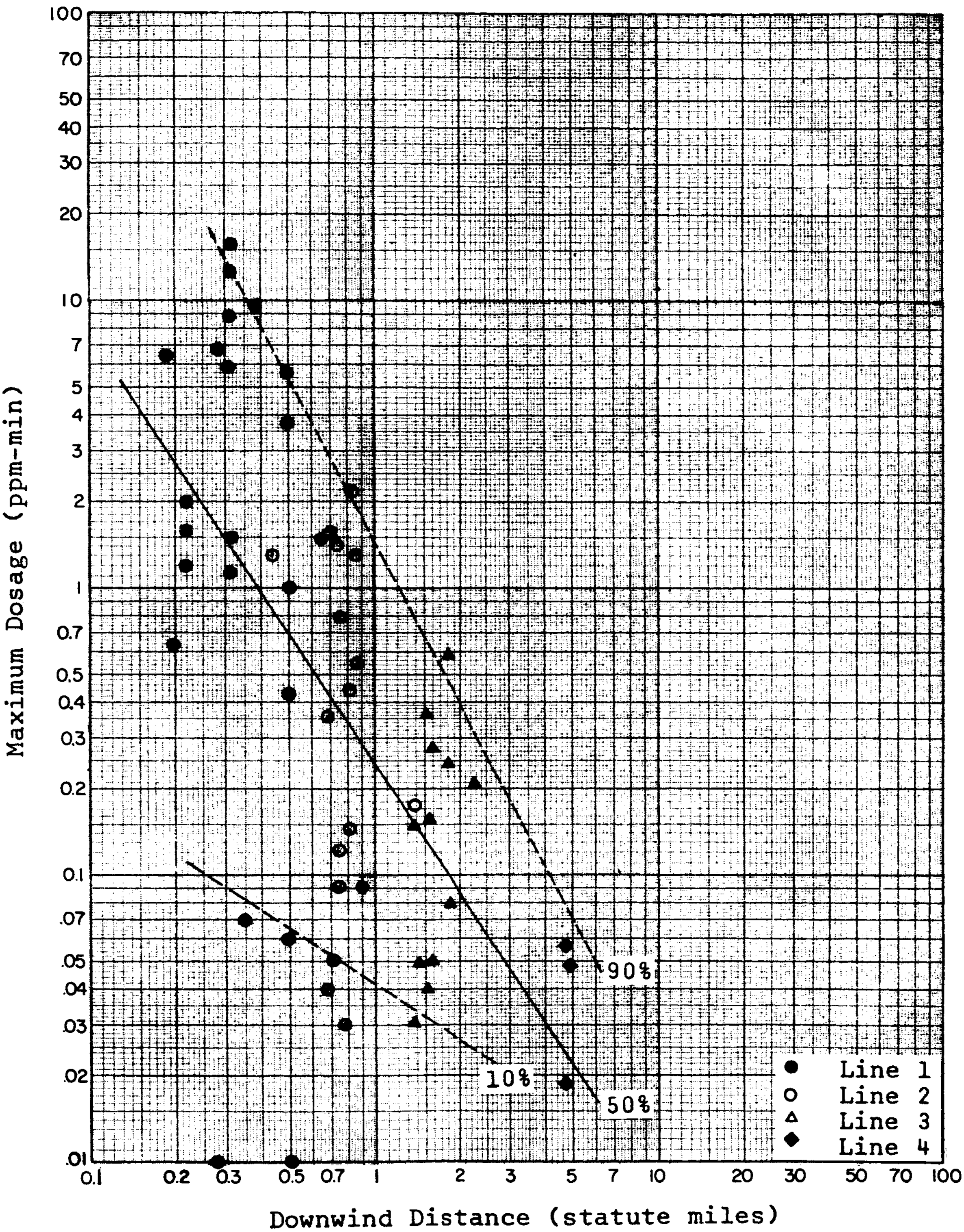


Fig. 25. OBSERVED DOSAGES FOR COLD SOURCES

delineating 10 per cent and 90 per cent of the observational data. These lines can be extrapolated to the boundary of the Sycamore Canyon property (two miles downwind) to give a median estimate of 0.08 ppm-minute per 100 pounds of F_2 release with a 90 per cent chance that the dosage would be less than 0.33 ppm-minute.

Data from the hot source trials are shown graphically in a similar form in Fig. 26. Median values for Lines 1 and 3 give the line marked "hot" in the figure. Also shown, for comparison, is the "cold" line taken from Fig. 25. It is suggested in Fig. 26 that the dosages are reduced for the hot source cases on Lines 1 and 2 with respect to the cold sources. On Line 3, however, the position of the median value is the same as for the cold sources, within the limits of the statistical variations. Thus, it is concluded that the dosages associated with the hot clouds are not significantly different from the cold cloud dosages at Line 3 or, by extrapolation, at the boundary of the property. The foregoing pertains to the hot source clouds of the size of the present trials. Larger heat sources than those used in the present program might result in significant dosage decreases downwind.

B. Analysis of FP Results

The variability in observed dosages shown in Fig. 24 is extreme by usual diffusion standards, particularlv close to the release on Line 1. It can only be explained by the center of the tracer cloud passing well over the sampling array of Line 1 with only the lower portion of the cloud affecting the samplers. The cloud would then constitute an elevated source in spite of the cold nature of the release.

The position of the S-2 site with respect to the sloping terrain immediately downwind appears to be responsible for this generation of an elevated source. Convection along the heated slope (southwest-facing) may result in a warm bubble

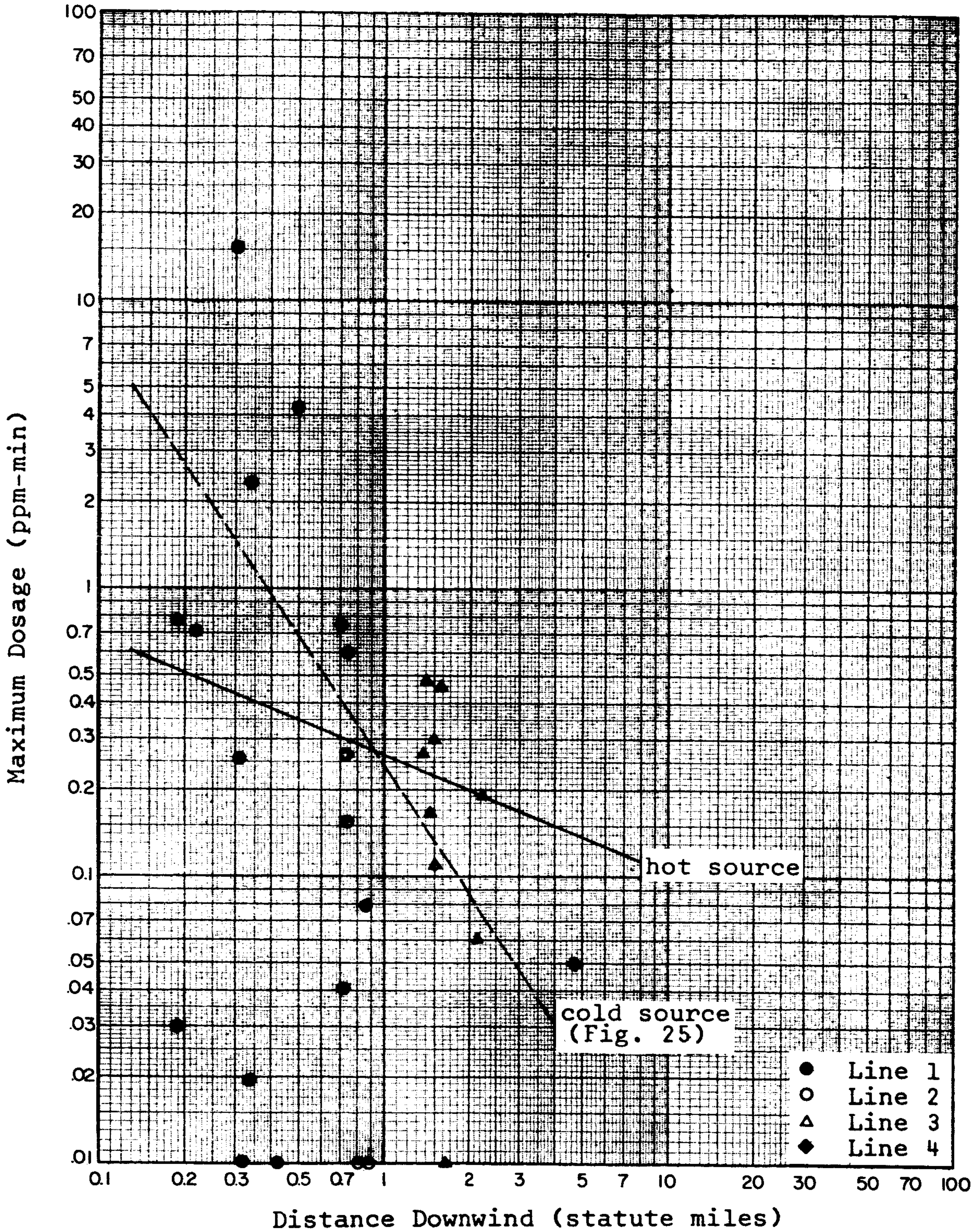


Fig. 26. OBSERVED DOSAGES FOR HOT SOURCES

of air rising above the ridge and traveling on downwind. Generation of heated bubbles on the slope is a generally random occurrence and it is suggested that the dosage values near the WIND line in Fig. 24 represent those cases when the tracer material was carried up the slope in the absence of a warm bubble.

At larger downwind distances, e.g. Line 3, all of the observed dosages are less than calculated. These data again represent the effect of an elevated source passing over the sampler line. In this case, a cloud center 600 feet above the ridge would explain the mean deviation of the observed dosages of Line 3 from the calculated values.

The comparative behavior of the hot clouds can also be considered in terms of an elevated source. At Line 1 the effect of the more buoyant cloud causes reduced dosages compared to the cold cloud as shown in Fig. 26. Further downwind, both hot and cold clouds appear to pass over the ridge at comparable altitudes so that ground sampler dosages are not significantly different.

The typical behavior of the two types of clouds is shown schematically in Fig. 27. Hot clouds generally rise more rapidly at the beginning of their downwind travel but the difference in elevation further downwind becomes much less significant. A major factor in this schematic picture is the frequent existence of an inversion at about 500 feet above the ridge which limits the upward travel of the hot cloud. In addition to this restriction, dilution of the hot clouds occurs rapidly for the small sources used in the test program. Larger initial heat sources might be able to penetrate the existing inversion or, in any event, the added buoyancy would tend to stratify the cloud in a layer at the base of the inversion. In either case, the equivalence of hot and cold clouds at Line 3 would no longer be expected.

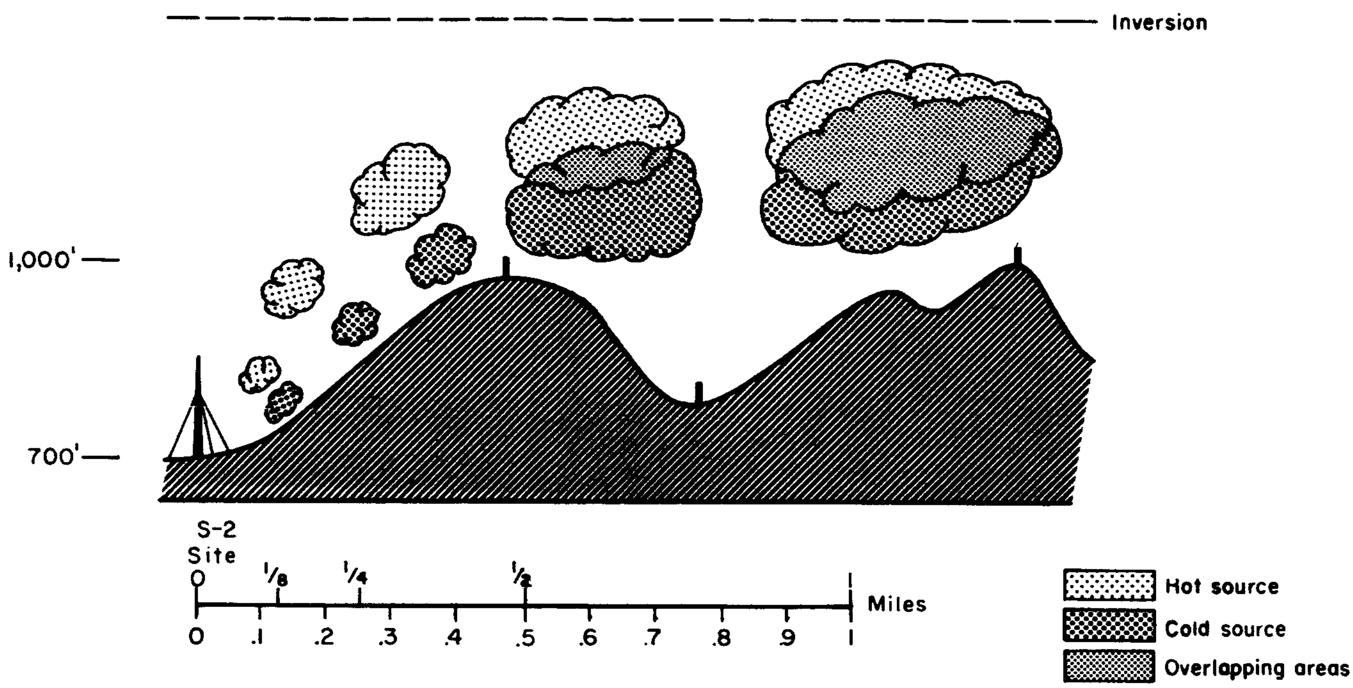


Fig. 27. COMPARISON OF HOT AND COLD SOURCE CLOUDS

The effect of the local terrain immediately surrounding S-2 on the cold clouds is quite significant. It is reasonable to assume that the WIND equation would approximate or underestimate the downwind dosage for a cold cloud under flat terrain conditions. Examination of Fig. 24 shows a factor of about 10 between the WIND calculations and the mean of the observed data for Line 3. The heated upslope motion near the source thus reduces the dosage downwind at the ridge by a considerable factor compared to the flat terrain condition. A similar reduction accompanies the generation of the hot cloud. In this case, however, it is reasonable to expect that the buoyant nature of the cloud itself provides most of the effect and that the behavior of the cloud over flat terrain might not be significantly different.

C. Height of Rise

Height of rise for an instantaneous hot cloud has been given by Hage and Bowne (1965) as:

$$H = 0.375 \left[\frac{Q}{\bar{u}\ (\Delta T+1/4)}\right]^{1/3}$$

where H is the height of rise in meters, Q is the heat source in calories, $\bar{u}$ is the average wind speed from the release point to the final height in meters/sec and ΔT is the temperature difference over the same height interval in °F.

According to General Dynamics/Convair calculations of heat released (from amount of charcoal consumed), Trials 24-28 represented heat sources of 770,000 to 5,400,000 BTU. Using an average velocity ($\bar{u}$) of six mph and an average ΔT of 7.2°F, this should result in a calculated rate of rise of about 3000 feet. In all of these trials (except Trial 24) the clouds reached the inversion before this altitude was reached so that the inversion height was the limiting factor in these cases.

Figures 28 and 29 show the vertical cross sections of the hot clouds as determined from the General Dynamics/Convair photographic measurements and are plotted on a downwind relief map of the area. Also shown are inversion heights and the highest cloud top observed by the aircraft. The vertical section of the cloud represents the last measured position from the General Dynamics/Convair photographs. The elevated nature of the cloud is clearly apparent as is the partial penetration of the inversion in several instances.

D. Inversion Penetration

Most of the literature describing the penetration of an inversion by a hot cloud deals with a continuous source such as a smokestack. The present problem, however, is concerned with an instantaneous source whose excess heat tends to be diluted more rapidly. The treatment most applicable, to the instantaneous source, was discussed by Saunders (1962) in relation to model tank experiments. The model developed by Saunders can be applied to a neutrally stable atmosphere topped by a layer of constant stability. In the real atmosphere there may be slight stability durations within the neutral layer but these have been neglected in the current discussion.

The principal parameters influencing the penetration, in Saunders' model, are the diameter of the cloud at the base of the inversion (D_1), the height of the base of the inversion (h), the rate of potential temperature increase within the inversion ($d\bar{\theta}/dz$) and the average excess potential temperature of the cloud at the time it reaches the inversion base ($\Delta\theta_i$). $d\bar{\theta}/dz$ and h can be obtained from vertical temperature sounding data. D_1 and $\Delta\theta_i$ have been computed as outlined in the following paragraphs.

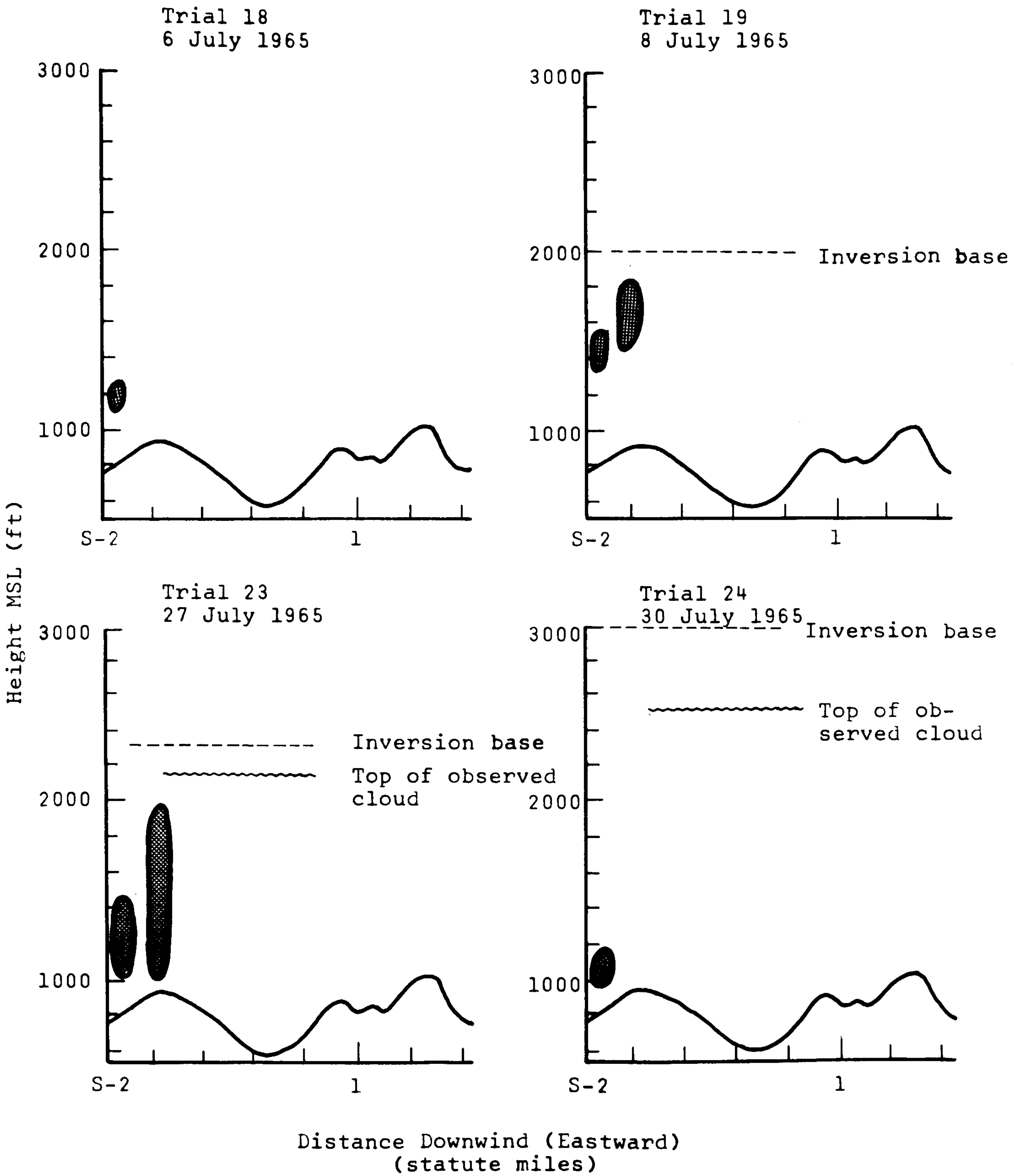


Fig. 28. VERTICAL CLOUD CROSS SECTIONS

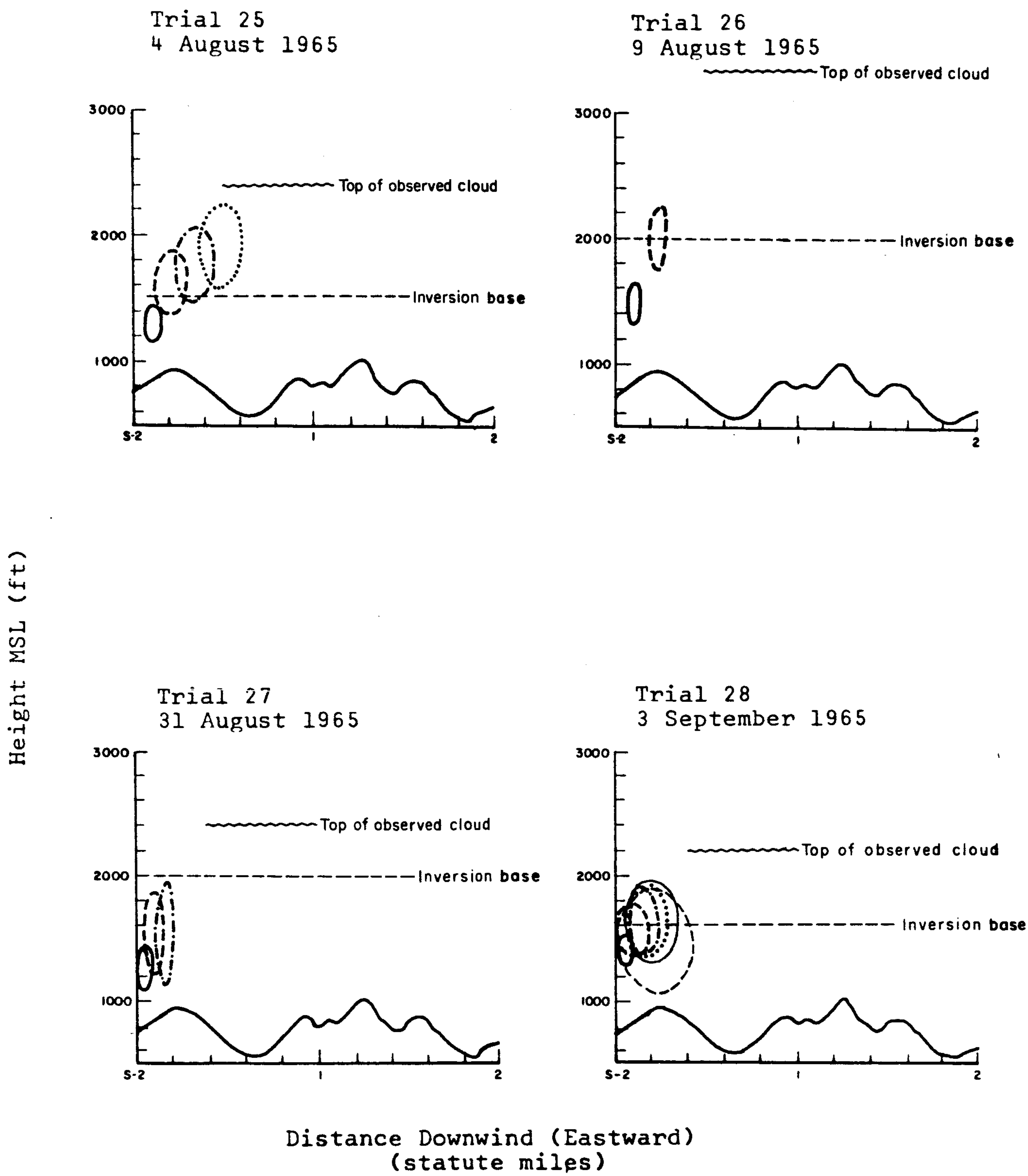


Fig. 29. VERTICAL CLOUD CROSS SECTIONS

D_1 can be considered to be related to the initial size of the source cloud (D_o) by the following expression which was suggested by Woodward (1959):

$$D_1 = D_o + h/2$$

This relation implies that the radius of the cloud increases linearly with height at an angle from the vertical of 26.5° as long as the environment is neutrally stable.

The average excess potential temperature of the cloud ($\Delta\theta_i$) is directly related to the vertical velocity of the cloud and has been evaluated from cloud position plots furnished by General Dynamics/Convair. The appropriate relationship is (Woodward, 1959):

$$w = C\,(g\bar{B}r)^{1/2}$$

where

w = vertical velocity

C = a constant determined experimentally at 1.2

g = gravity acceleration

$\bar{B}$ = mean buoyancy of the cloud = $\Delta\theta_i/\theta_e$

r = horizontal radius of the cloud

θ_e = potential temperature of the environment

The average excess potential temperatures, sufficient to explain the observed vertical cloud velocities, are plotted for each trial in Figs. 30 to 33 as a function of height above the release point.

Using the parameters of initial cloud diameter (D_o), excess cloud temperature at the inversion ($\Delta\theta_i$), height of the inversion (h) and rate of increase of potential temperature within the inversion ($d\bar{\theta}/dz$) it is possible to estimate the penetration of the inversion by means of the nomogram given in Fig. 34. This nomogram has been constructed

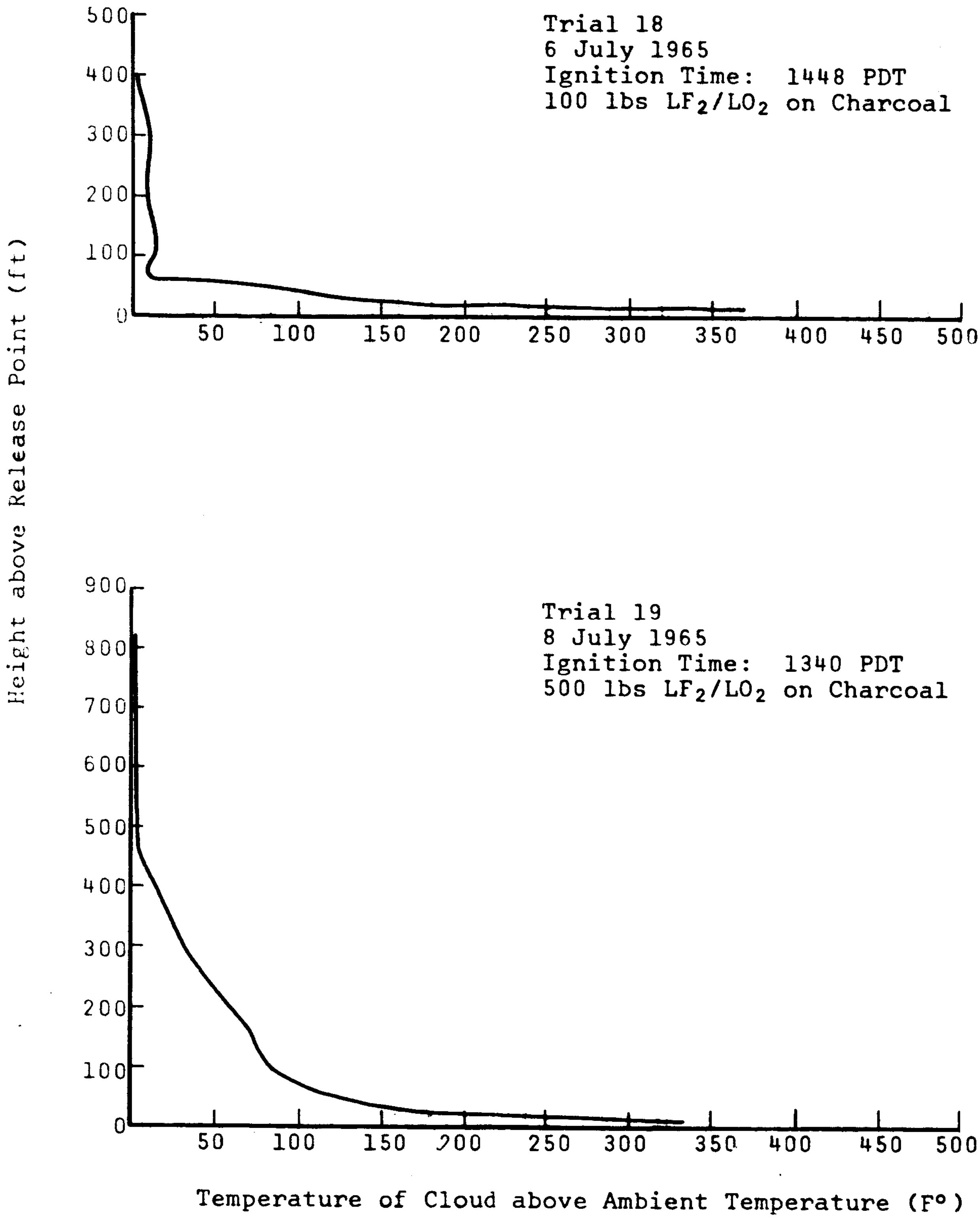


Fig. 30. CLOUD TEMPERATURES

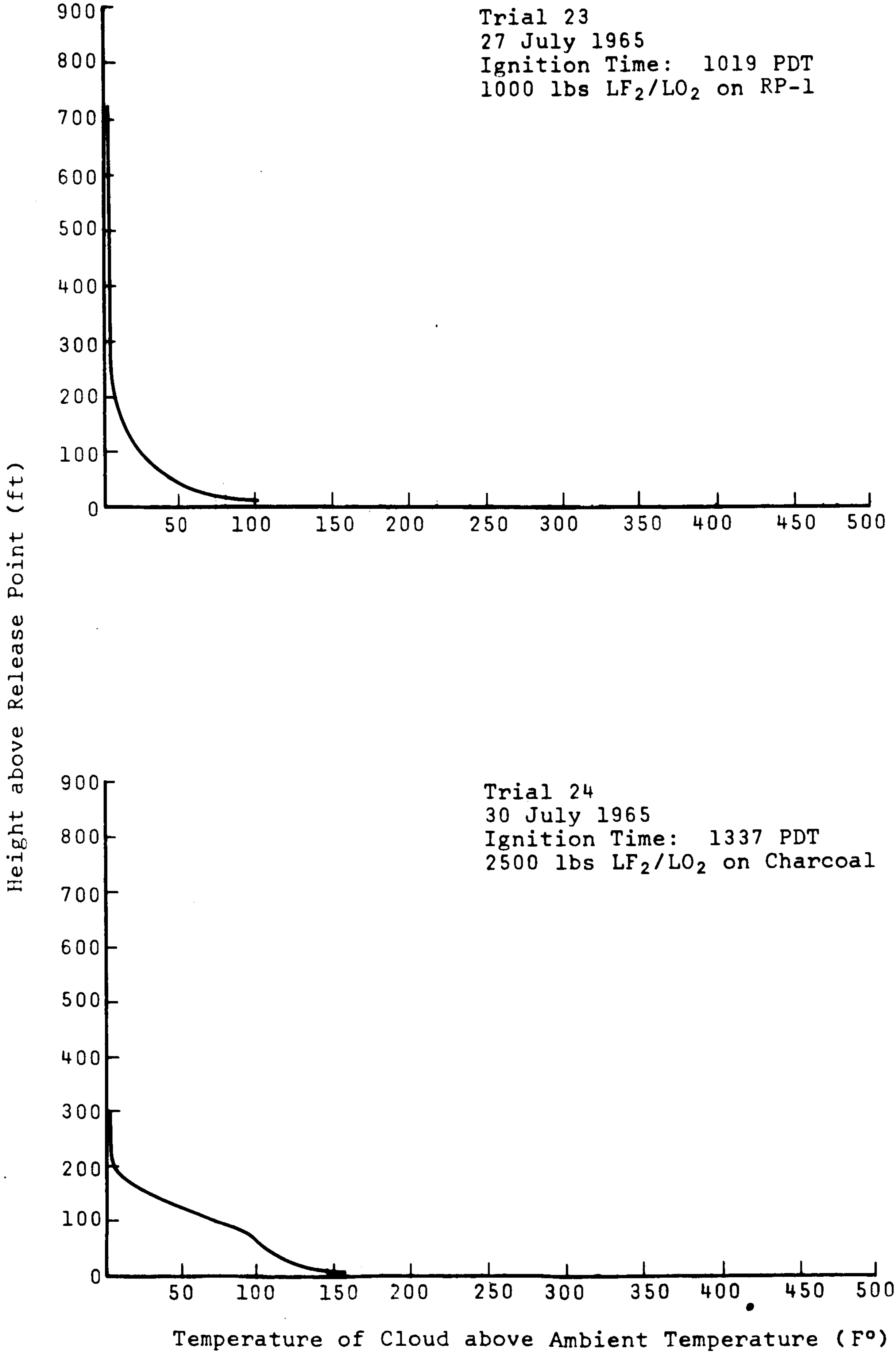


Fig. 31. CLOUD TEMPERATURES

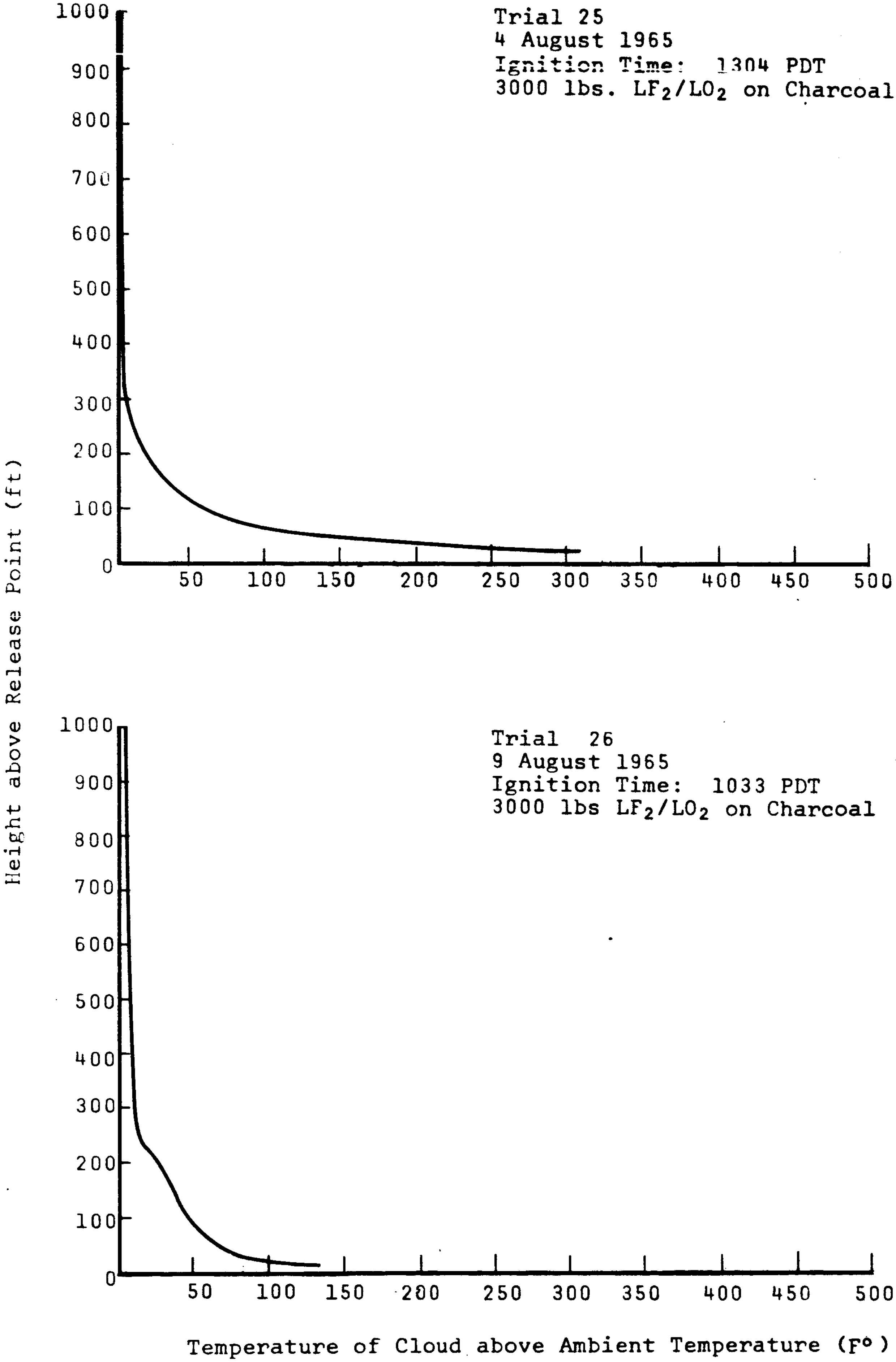


Fig. 32. CLOUD TEMPERATURES

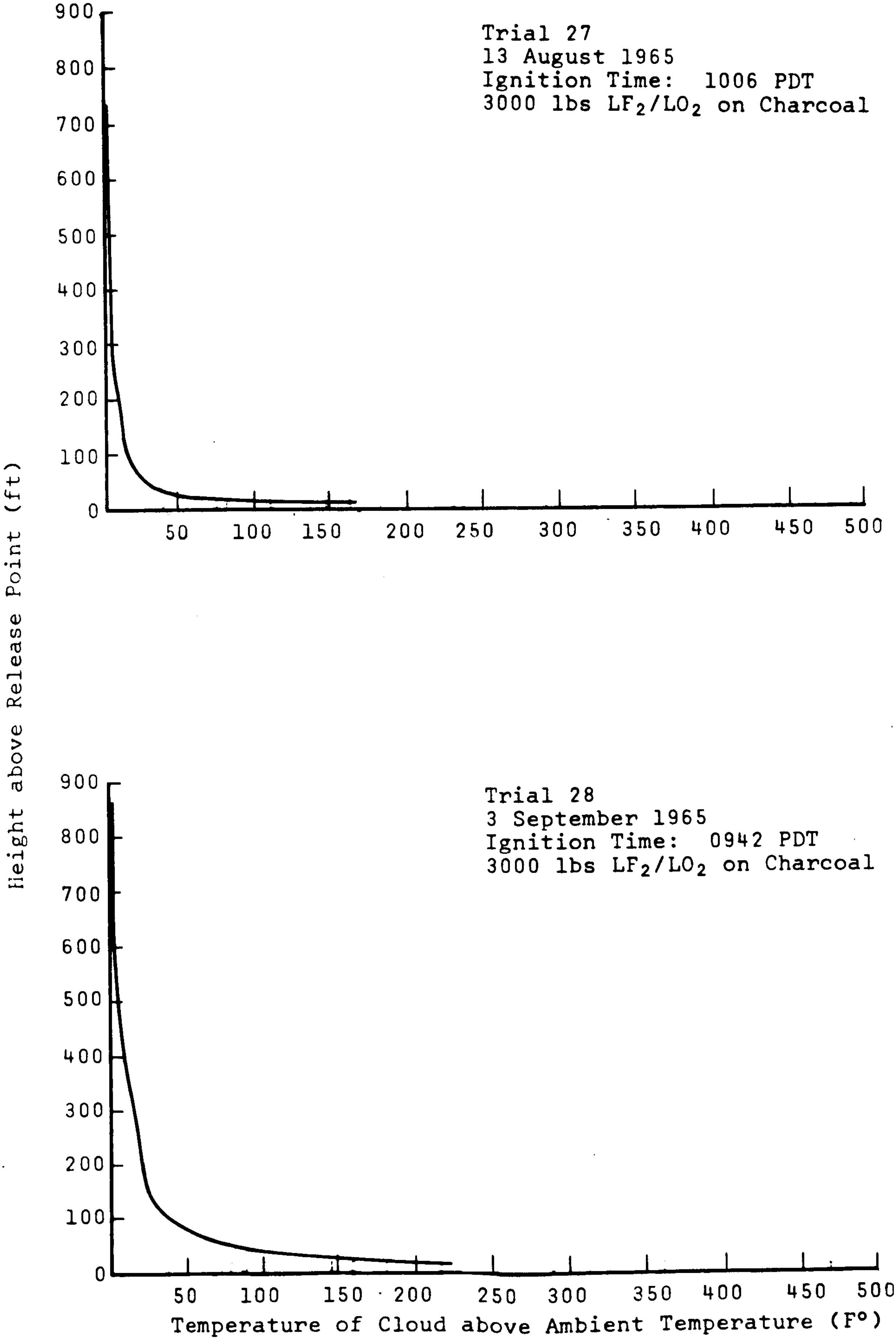


Fig. 33. CLOUD TEMPERATURES

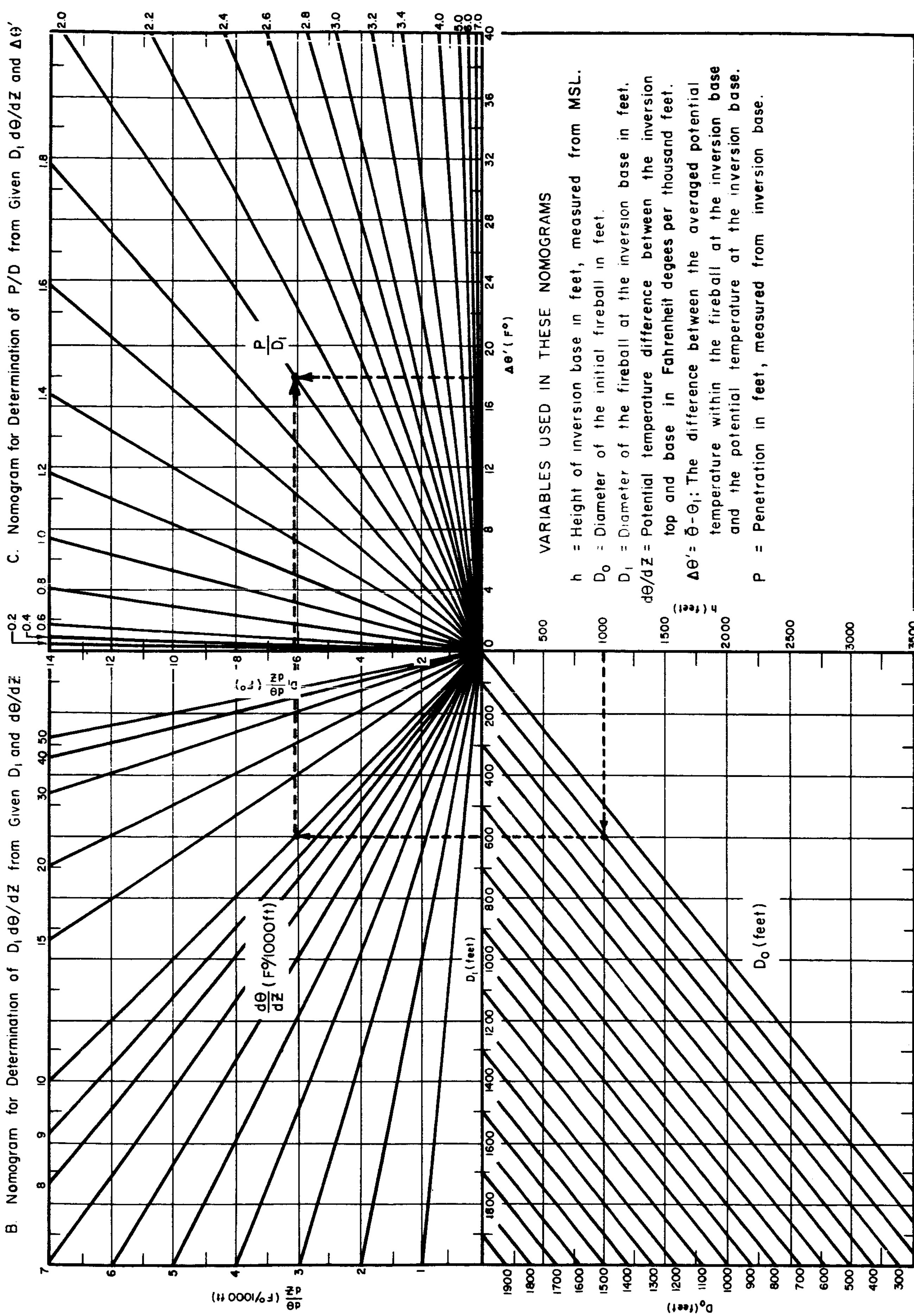


Fig. 34. DETERMINATION OF PENETRATION FOR SURFACE RELEASE

from the model given by Saunders. A sample calculation is outlined on the nomogram and given below:

Let $h = 1000$ feet

$D_o = 100$ feet

$\Delta\theta_i = 18°F$

$d\bar{\theta}/dz = 10F°/1000$ feet

The procedure for using the nomogram is as follows:

1. Enter D_o and h in A to give $D_1 = 600$ feet for the diameter of the cloud at the inversion.
2. Extend $D_1 = 600$ feet into B until it meets the line of $d\bar{\theta}/dz = 10F°/1000$ feet. This point gives $D_1\ d\bar{\theta}/dz = 6F°$ on the vertical scale of B.
3. Use $\Delta\theta_i = 18°F$ and $D_1\ d\bar{\theta}/dz = 6F°$ as coordinates in C. This point gives a value of $P/D_1 = 2.0$.
4. Multiply P/D_1 by D_1 to obtain $P = 1200$ feet, for the cloud penetration into the inversion.

The nomogram does not include the magnitude (in °F) of the inversion as a parameter. In the example discussed above it is tacitly assumed that the inversion magnitude is greater than 18°F. In this case, the cloud would penetrate 1200 feet before its excess heat was dissipated. However, if the inversion magnitude were less than 18°F, the cloud would break through the inversion and the cloud rise might be considerably more than the calculated value of 1200 feet.

The following table shows the excess temperatures inferred from the cloud vertical velocities together with other pertinent information for the calculation of penetration:

TABLE III

CLOUD PENETRATION CALCULATIONS

Trial Number	$d\bar{\theta}/dz$ (°F/1000 ft)	D_o (ft)	$\Delta\theta_i$ (°F)	Height of Inversion (ft)	Calculated Penetration (ft)
19	6.1	85	0.5	1300	300
23	16.0	122	0.4	1600	170
24	5.0	153	0.2	2300	250
25	20.0	100	0.5	800	150
26	5.8	123	2.7	1300	740
27	27.5	110	0.5	1300	70
28	36.7	143	0.5	900	55

These data show that the clouds had very small excess temperatures when they arrived at the inversion base. Penetrations into the inversions should be correspondingly small.

The following table gives the top of the smoke cloud as observed from the aircraft, together with the elapsed time after release of the observation. All heights are measured with respect to the S-2 site.

TABLE IV

COMPARISON OF OBSERVED AND CALCULATED PENETRATIONS

Trial Number	Top of Smoke Cloud (feet)	Minutes After Release	Height of Inversion (feet)	Calculated Penetration (feet)
23	800	15	1600	1770
24	1800	4	2300	2550
25	1700	6	800	950
26	2700	13	1300	2040
27	1700	7	1300	1370
28	1500	6	900	955

The table shows that a degree of penetration was achieved with all of the 3000-pound hot sources (Trials 25 to 28). According to the aircraft observations, the smoke did not reach the inversion base on Trials 23 and 24. For Trials 25-28 the top of the smoke cloud exceeded the calculated penetration height by 400-700 feet. The calculated penetration, however, refers to the center of the cloud while the observations refer to the top of the cloud. At heights of 1000 feet the vertical diameter of the cloud was measured at 500-800 feet. Consequently, the calculated penetrations for the 3000-pound hot sources are in reasonable agreement with observations.

The following table shows the excess temperatures of the hot clouds at the inversion base (calculated from the vertical velocity data) compared to the magnitude of the inversion involved:

TABLE V

COMPARISON OF CLOUD TEMPERATURES AND INVERSION MAGNITUDES

Trial Number	Calculated Cloud Temperature Excess (°F)	Inversion Magnitude (°F)
19	0.5	5.5
23	0.4	8.0
24	0.2	1.0
25	0.5	4.0
26	2.7	3.5
27	0.5	5.5
28	0.5	11.0

In each case, it is seen that the excess temperature of the cloud was insufficient to break through the inversion. As a consequence, the upward cloud growth was limited to the inversion layer itself.

E. Extrapolation to Larger Sources

The Sycamore Canyon trials utilized maximum heat sources represented by 3000 pounds of oxidizer. Partial penetration of the inversion was achieved on several instances but a break through the inversion was not accomplished. It is of interest to attempt an estimate of the heat source required for this purpose from the experience of the present program. Unfortunately, two major factors concerned with the initial formation of the cloud make this extrapolation difficult, i.e. initial cloud dimensions and combustion efficiency. Data from a larger hot source at Edwards AFB, however, provide a means for obtaining additional information.

Tucker (1965) reports on the phototheodolite (position and size) data as well as the meteorological environment data for the Saturn S-IV test at Edwards. Total fuel involved amounted to 91,000 pounds of LH_2-LO_2. Following the procedures given in a previous section, Fig. 35 was plotted to show the excess cloud temperatures required to explain the observed vertical cloud velocities. Excess temperature at 800 feet amounted to 41°F and 11°F at 1800 feet.

In the Sycamore Canyon area 50 per cent of the inversions are below 800 feet above the S-2 site and 97 per cent are below 1800 feet. In addition, 50 per cent of those inversions below 1800 feet have a magnitude of 12.0°F or less and 84 per cent have a magnitude of 17°F or less. It is therefore apparent that a hot source of the Saturn S-IV type would break through at least half of the inversions with the Sycamore Canyon conditions. For 800-foot inversions or less, the excess temperatures should be sufficient to break through in virtually all cases.

More definitive extrapolation of the Sycamore Canyon and Saturn data is not warranted, at present, for intermediate size clouds. Penetrations of the inversion are

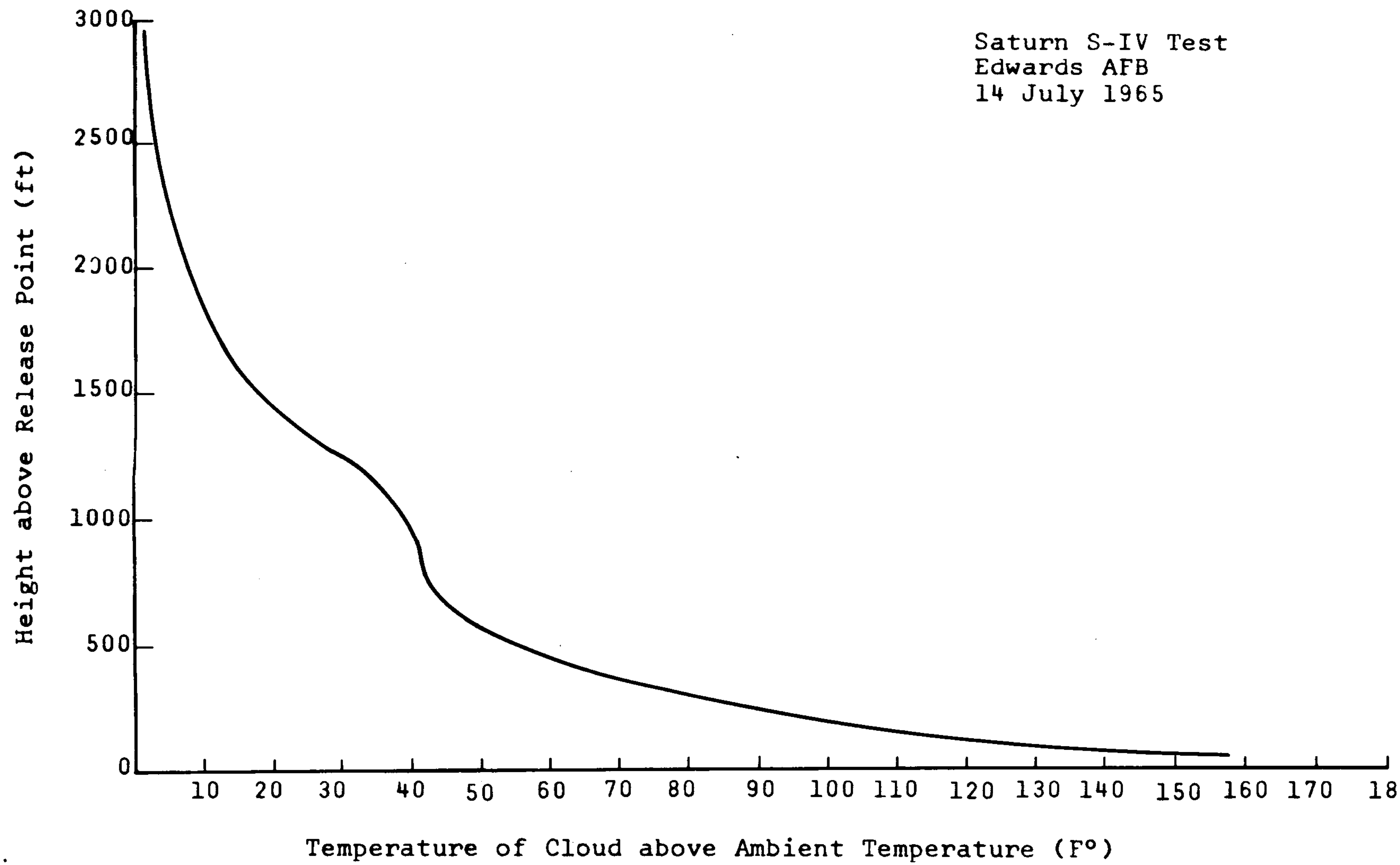


Fig. 35. CLOUD TEMPERATURES

critically dependent on initial cloud size and cloud temperatures. The following table shows average temperature at 200 feet above the site as calculated from vertical cloud velocity together with observed cloud dimensions (D^3_{avg}) at the same height.

TABLE VI

INITIAL CLOUD PARAMETERS

Trial Number	ΔT (°F)	D^3_{avg} (ft^3)	Oxidizer Amount (pounds)
18	9.0	1.03×10^6	100
19	55.8	1.19×10^6	500
23	3.6	1.49×10^7	1,000
24	3.6	2.23×10^7	2,500
25	16.2	9.94×10^6	3,000
26	23.4	9.28×10^6	3,000
27	7.2	1.46×10^7	3,000
28	19.8	1.15×10^7	3,000
Saturn	90.0	1.40×10^7	70,000

The table shows a trend toward higher ΔT's and larger cloud sizes as the amount of oxidizer (and heat released) is increased. There is considerable variation, however, in the data and it would not be wise to interpolate for intermediate size heat sources. In particular, the small sources of Trials 18 and 19 showed relatively high cloud temperatures (and high initial vertical velocities).

In part, the variability in Table VI must result from initial combustion conditions. At Sycamore Canyon, the charcoal pit was varied in size so that the initial cross-sectional area of the cloud varied substantially. This, in turn, affected the combustion efficiency in a complex and unknown manner. Figure 36 is an attempt to generalize the data shown in Table VI. $\Delta T \times D^3_{avg}$ has been plotted as

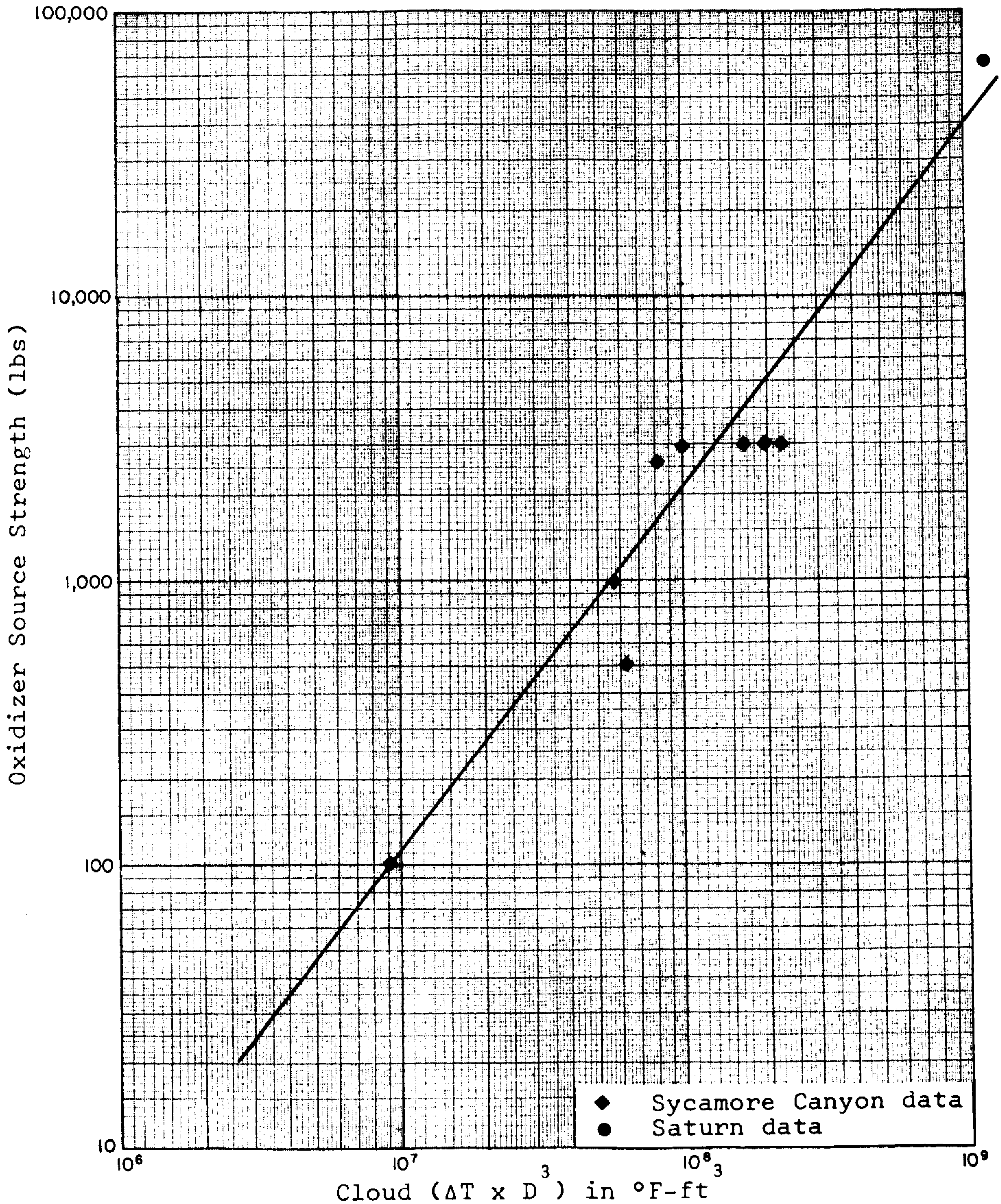


Fig. 36. EFFECT OF SOURCE STRENGTH ON CLOUD PARAMETERS AT 200 FEET

a function of oxidizer amount. This parameter represents a measure of the total excess heat within the cloud at a time well beyond the end of the radiation phase. A rough relationship appears to exist which may suggest the following comments:

1. Initial conditions (e.g. Trials 18 and 19) may exist which limit the cloud dimensions but these are accompanied by relatively high cloud temperatures such that $\Delta T \times D_0{}^3$ maintains a relationship of the form shown in Fig. 36.
2. The product $\Delta T \times D_0{}^3$ increases rapidly with increasing oxidizer amount in a manner which results in larger cloud temperatures and higher initial vertical cloud velocities.

It is apparent that Fig. 36 should be plotted in terms of heat of combustion, rather than oxidizer amount but uncertainties regarding combustion efficiency have not permitted this type of analysis.

F. Utilization of the Sycamore Canyon Site

The present program has been aimed at evaluating the potential for LF_2 testing at the S-2 site in the Sycamore Canyon area. It has been indicated that each 100 pounds of F_2 released from the site would result in a median dosage of about 0.08 ppm-min at the eastern boundary of the property (about two miles). In 90 per cent of the test conditions this dosage would have been less than 0.33 ppm-min. At a distance of four miles from S-2 the corresponding dosages would be 0.03 and 0.10, respectively. This conclusion applies to meteorological conditions as they were encountered during the program, i.e. wind directions from southwest to northwest, wind speeds greater than 2.5 miles per hour, trials conducted between 10 A.M. and 4 P.M. with moderate to strong solar insolation. For these conditions and the hot sources employed during the test program (up to 3000 pounds of oxidizer) there was no significant difference between the hot and cold cloud dosages at the last sampling line about one and one-half miles from the release.

In accordance with the criteria specified in NASA Memorandum dated 10 May 1965, the limiting amounts of F_2 which could be released at the S-2 site would be about 6000 pounds for 50 per cent of the cases and 1500 pounds if the chance of exceeding five ppm-min at the boundary is not to exceed 10 per cent. If the criterion for HF (50 ppm-min) is used, the limiting release amounts could be increased by a factor of 10.

Stratification of the observed dosage data in terms of measured meteorological parameters was not productive, presumbably because of the rough terrain and the tendency for the clouds to be elevated after passing the first ridge downwind of the S-2 site. The factors influencing this variability are likely to be primarily local in nature, involving the canyon environment surrounding the site and the heating of the slope downwind of the site. As a consequence, improvement in the dosage predictions to take advantage of favorable weather and increase the utility of the site beyond the limits given above will require additional knowledge of the meteorological environment in the vicinity of the S-2 site. Operationally, detailed instrumentation in the vicinity and careful meteorological analysis could probably be needed before this could be accomplished.

No trials were conducted with inversion heights below 1500 feet MSL or 500 feet over the second downwind ridge. Although no pronounced effect of inversion height on observed dosages was noted, it is reasonable to expect that dosages at the boundary might increase as the gap between the ridge and the base of the inversion decreased below

500 feet. As a consequence, it is recommended that trials not be conducted with inversions less than 1500 feet MSL unless the scale of the trials takes into account the possibility of increased dosages at the boundary of the property.

The preceding paragraphs indicate that inversion bases below 1500 feet MSL should be the principal meteorological factor leading to non-operational days. Wind speed, solar radiation and time of day limitations should be secondary factors and will, to some extent, be dependent on inversion height. Figure 18 indicates that inversion heights at 4 P.M. PST should be less than 1500 feet on 30-50 per cent of the days during the year.

In summary, it is suggested that a release of 6000 pounds of F_2 represents the median condition for fulfillment of the NASA marginal criteria at the boundary of the property under the meteorological conditions of the test program. These conditions should occur on about 50 and 70 per cent of the days during the year. On the remaining days, the inversion base should be less than 1500 feet and dosages are likely to be increased at the boundary compared to the median condition.

Operational use of the Sycamore Canyon site would require additional meteorological instrumentation, particularly within the area immediately surrounding the S-2 site. Wind speed and direction should be provided at about 10 feet near the base of the gantry to observe the low level flow near the release point. Additional wind speed and direction units would be required at the top of the gantry and at the highest point on the ridge immediately downwind of the site. ΔT should be measured on the gantry in order that low level stability within the canyon can be avoided. Inversion heights present a problem since the only readily available data are twice-a-day observations from Montgomery Field (0400 and 1600 PST). For many operational conditions, the height can be estimated for the day from the Montgomery Field observations. Requirements for more refined dosage estimates might dictate occasional use of a rented light aircraft for those inversion situations where marginal conditions are expected.

VI. CONCLUSIONS

1. Tracer releases from the S-2 site without heat sources showed extreme variability in dosages, particularly at the first ridge immediately downwind. Median dosages were considerably less than those estimated from existing diffusion models such as the WIND equation or the turbulence ($3i^2$) model. It is suggested that the tracer clouds were lifted upward along the slope downwind of the S-2 site and hence represent elevated source clouds during their subsequent downwind travel.

2. Tracer releases into hot source clouds yielded lower dosages at the first sampling line immediately downwind of the S-2 site. Further downwind at the third sampling line (one and one-half miles), dosages associated with cold and hot sources were similar. The hot source cloud apparently can be considered as a more elevated source at the first ridge but further downwind, limited upward growth of the hot cloud due to mixing and the presence of the inversion reduce the difference between cold and hot clouds to an insignificant amount. This comparison applies only to the hot source magnitudes used in the present program. Larger heat sources might penetrate the inversion or produce clouds which spread out in a layer along the base of the inversion. The comparative results of the hot and cold sources also only pertain to the Sycamore Canyon area where local terrain causes the cold cloud to take on an elevated configuration as it moves downwind.

3. Based on the results of the tracer studies, a release of 100 pounds of F_2 would produce a median dosage of 0.08 ppm-min at the boundary of the property. Ninety per cent of the dosages experienced at the boundary should be less than 0.33 ppm-min. If the contaminant reaching the boundary were considered to be HF, the corresponding dosages should be increased by a factor of two. Using these

figures and the NASA criterion of five ppm-min for F_2 a release of 6000 pounds would be allowable on a median basis and 1500 pounds on a 90 per cent basis. If the contaminant is treated as HF at the boundary and a criterion of 50 ppm-min is used, the allowable release would become 30,000 pounds on a median basis and 7500 pounds for a 90 per cent expectancy.

4. The results of the tracer trials did not indicate that dosage estimates at the boundary could be improved substantially by the use of simple meteorological parameters. Distance from the source remained as the principal estimating parameter. It appears that the local meteorological environment of the canyon in which S-2 is located is of very considerable importance in determining downwind distributions. Further refinements in dosage prediction will require a more detailed study of this meteorological environment.

5. Partial penetration of the inversion was achieved on four of the trials, all with 3000 pounds of oxidizer. No break through the inversion was accomplished. Cloud temperatures calculated from the rate of rise of the Saturn S-IV test indicate that a source of this magnitude would penetrate nearly all of the inversions normally expected at Sycamore Canyon.

6. No trials were conducted in the present program with an inversion below 1500 feet (800 feet above the site). Lower inversions should result in higher dosages at the downwind boundary of the property. The criteria given above for allowable releases pertain only with inversions at 1500 feet or above. These conditions occur 50-70 per cent of the time in the Sycamore Canyon area. Additional requirements are suggested, i.e. winds from the southwest to northwest, wind speeds higher than 2.5 miles per hour and trials between 10 A.M. and 4 P.M.

7. Instrumentation required for operational use at Sycamore Canyon should include wind speed and direction at about 10 feet near S-2, wind speed and direction at the top of the gantry and wind speed and direction at the highest point of terrain available. ΔT should be observed over the depth of the gantry. Inversion heights will have to be obtained twice a day from Montgomery Field.

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APPENDIX

DATA SUMMARY

This Appendix contains the data from the Sycamore Canyon program. Included are the FP Dosages, Meteorological Data and Aircraft Temperature Soundings.

All FP dosages have been adjusted to compare with a release of 100 pounds of F_2 in units of ppm-m in. The color of FP released is noted on each sheet (Y-yellow or G-green) just before each FP release time. For the trials having smoke releases, the path of the center of the smoke plume is shown by a broken arrow with a stippled area showing the horizontal extent of the smoke, when discernable in the photographs. On the "hot" trials, a broken circle is used to show the location and size of the smoke "ball" at regular intervals following the ignition.

The meteorological data generally covers the period starting at least five minutes before a release and continuing for an hour after the completion of the release. All heights are above the ignition pad and times are PDT. The σ_{30} are from direct readout of the corresponding strip charts as recorded. When the σ_{30} readout was not available, the σ_{300} was estimated from the analog trace. All units are in the key in the upper left portion of the page.

The aircraft temperature soundings are included in plotted form. The points included as solid circles are the temperatures on the S-2 Gantry at the time of the sounding. The temperatures on the gantry at the release or ignition time are shown as solid triangles.

Conversion of FP Dosages to F_2

An effective number of 5.02×10^{12} particles of FP were released on each trial. FP dosages (D_1) obtained at each sampler therefore require normalizing by this factor:

$$\text{Normalized dosage} = \frac{D_1}{5.02 \times 10^{12}} \left(\frac{\text{min}}{\text{liter}}\right).$$

If a hypothetical release of 100 pounds of F_2 had been released instead of the FP, the dosage at the sampler would amount to:

$$F_2 \text{ dosage} = \frac{100\ D_1}{5.02 \times 10^{12}} \left(\frac{\text{lbs-min}}{\text{liter}}\right).$$

To obtain the F_2 dosage in ppm it is required to convert pounds of F_2 to the equivalent volume of F_2 by means of:

38 g of F_2 occupy 22.4 liters at standard conditions.

The converted F_2 dosage then becomes:

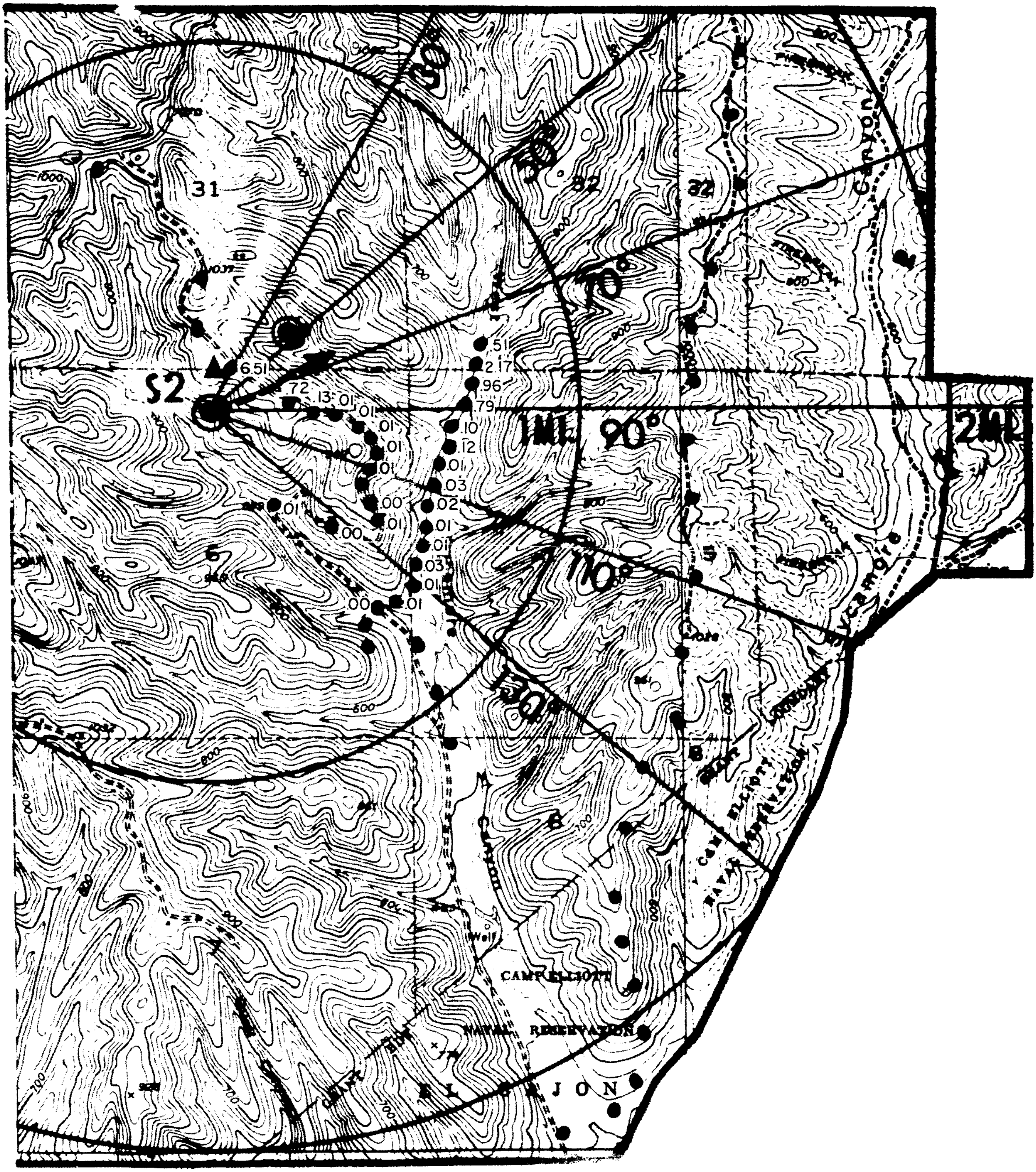
$$F_2 \text{ dosage} = \frac{100\ D_1}{5.02 \times 10^{12}} \times 453 \left(\frac{22.4}{38}\right) \left(\frac{\text{liter-min}}{\text{liter}}\right)$$

$$= 5.31 \times 10^{-3} D_1 \text{ ppm-min (by volume).}$$

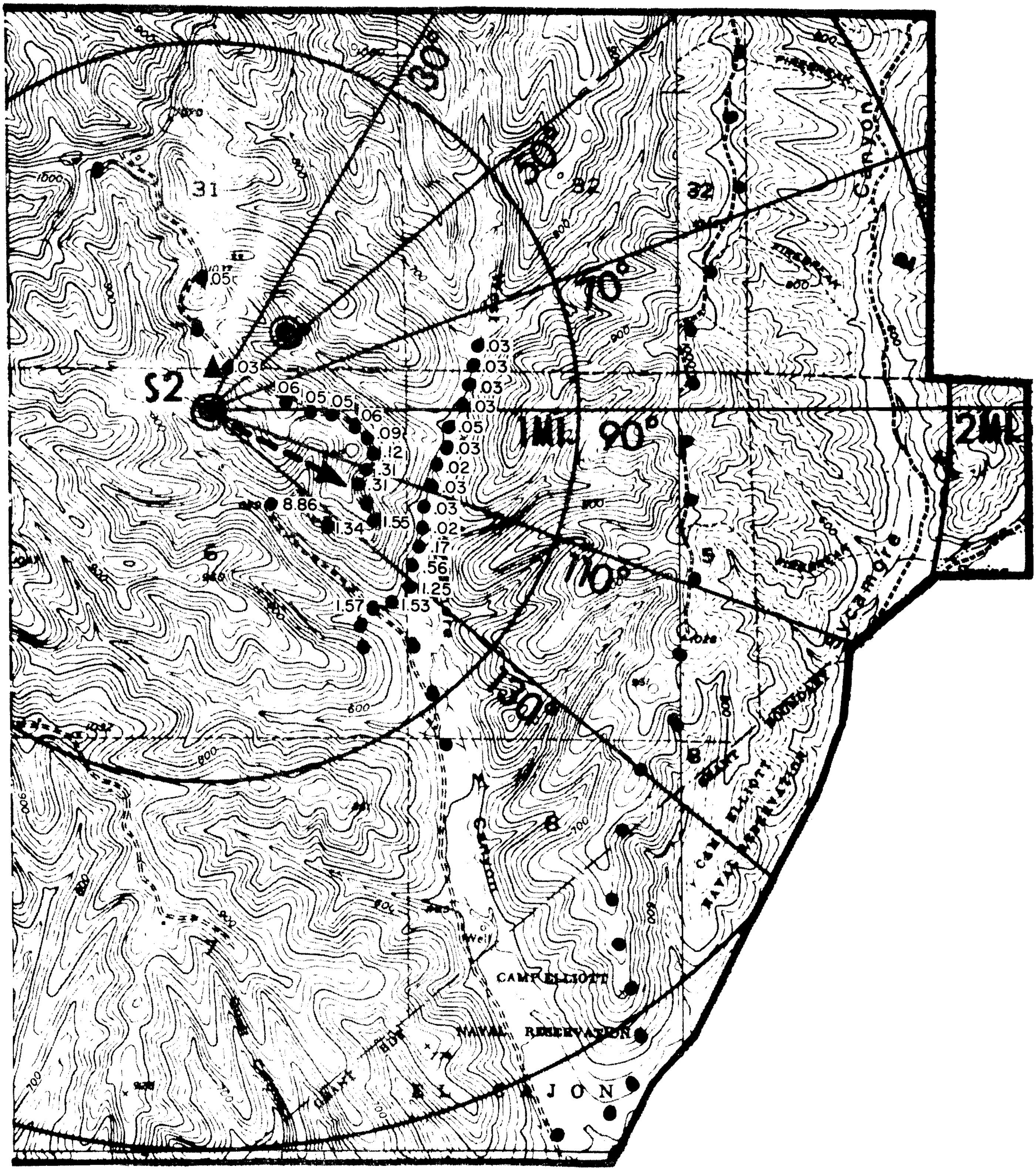
If a release of 100 pounds of HF is assumed, the converted HF dosage would be:

$$\text{HF dosage} = 5.31 \times 10^{-3} D_1 \left(\frac{38}{20}\right) = 1.012 \times 10^{-2} D_1 \text{ ppm-min.}$$

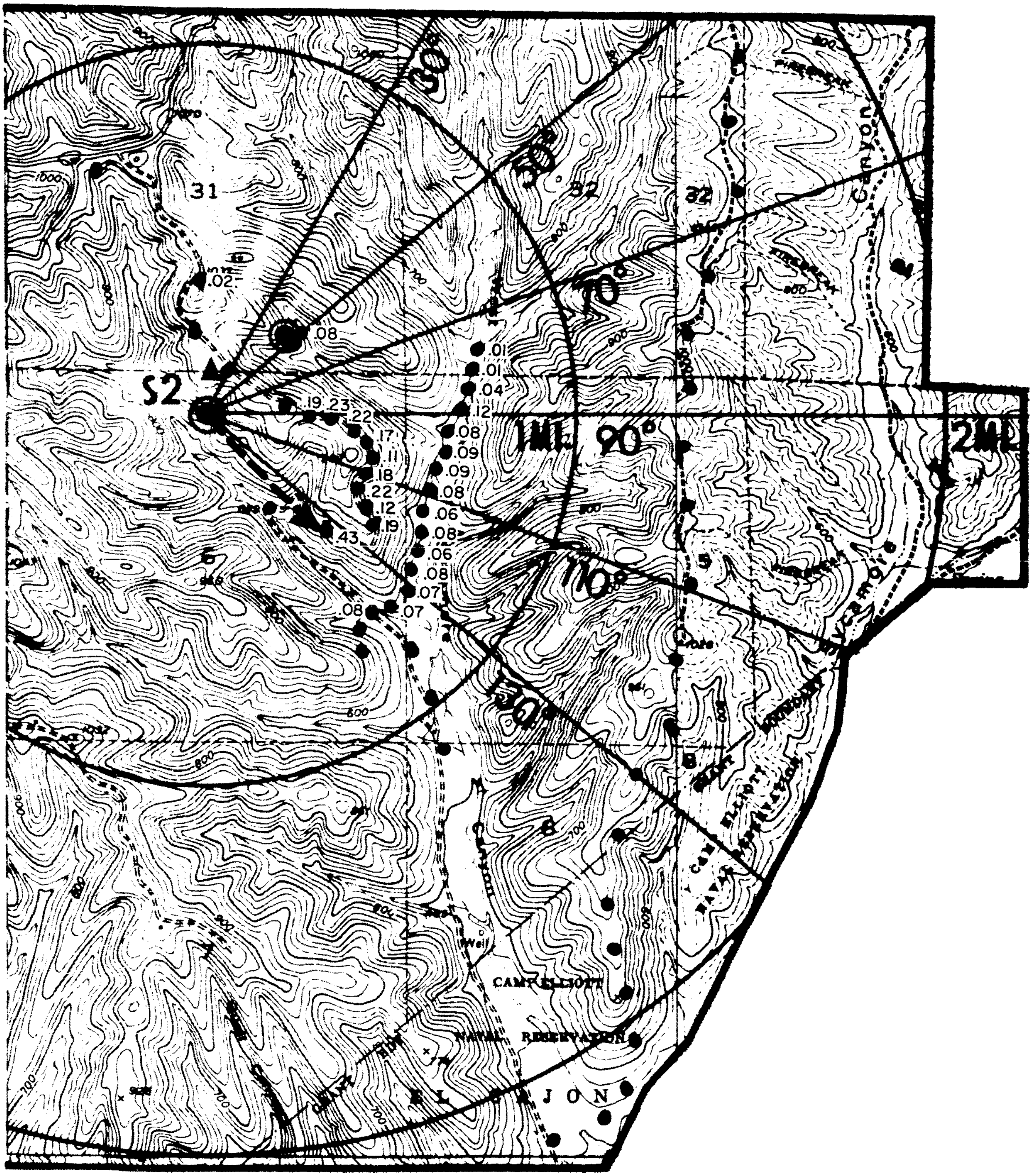
The WIND equation is normally given in terms of peak cross-wind concentration for a given rate of release. The equation can also be used for a total dosage estimate by entering the equation with a total release amount instead of a rate. The WIND equation itself was actually derived from total dosage data and later applied to the continuous release mode. In order to compare the results of the Sycamore Canyon releases with calculations from the WIND equation, the WIND system was used in its total dosage form.



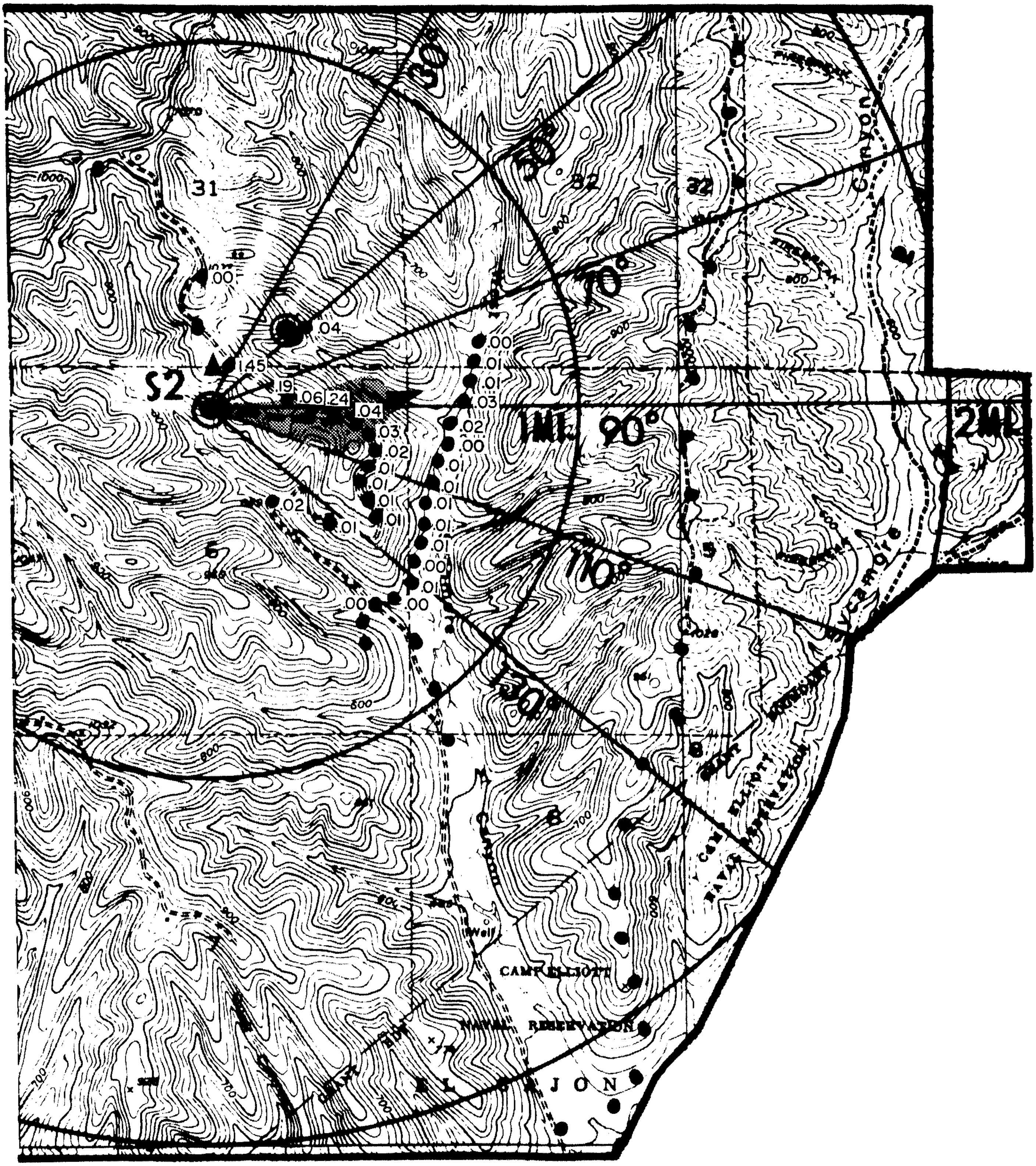
Trial: 1
Date: 27 April 1965
FP Release (Y): 1815-1816.5 PDT
Dosages: ppm-min for 100 lbs F_2



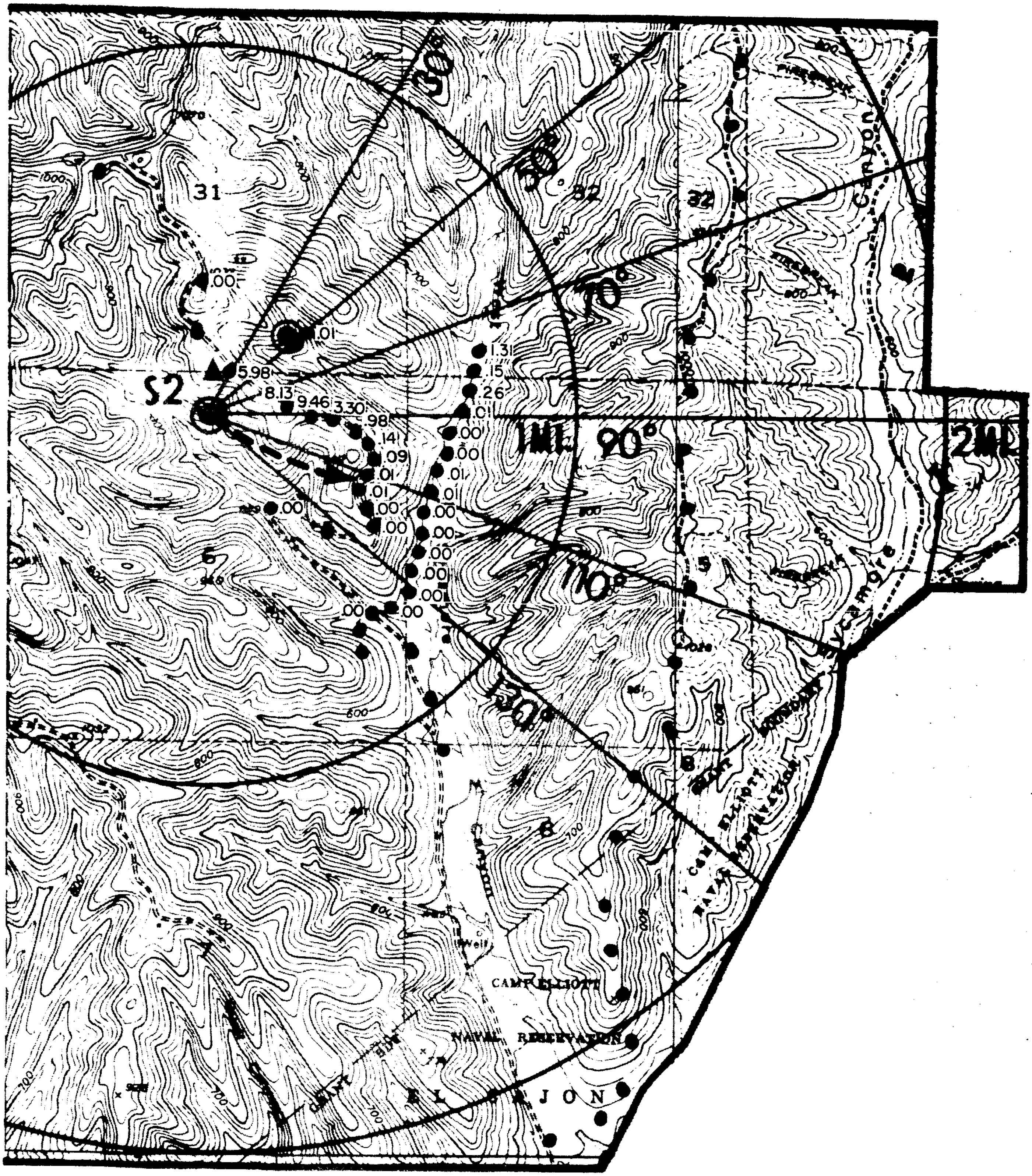
Trial: 2
Date: 28 April 1965
FP Release (Y): 1123-1124.5 PDT
Dosages: ppm-min for 100 lbs F_2



Trial: 3
Date: 28 April 1965
FP Release (Y): 1307-1308.5 PDT
Dosages: ppm-min for 100 lbs F_2

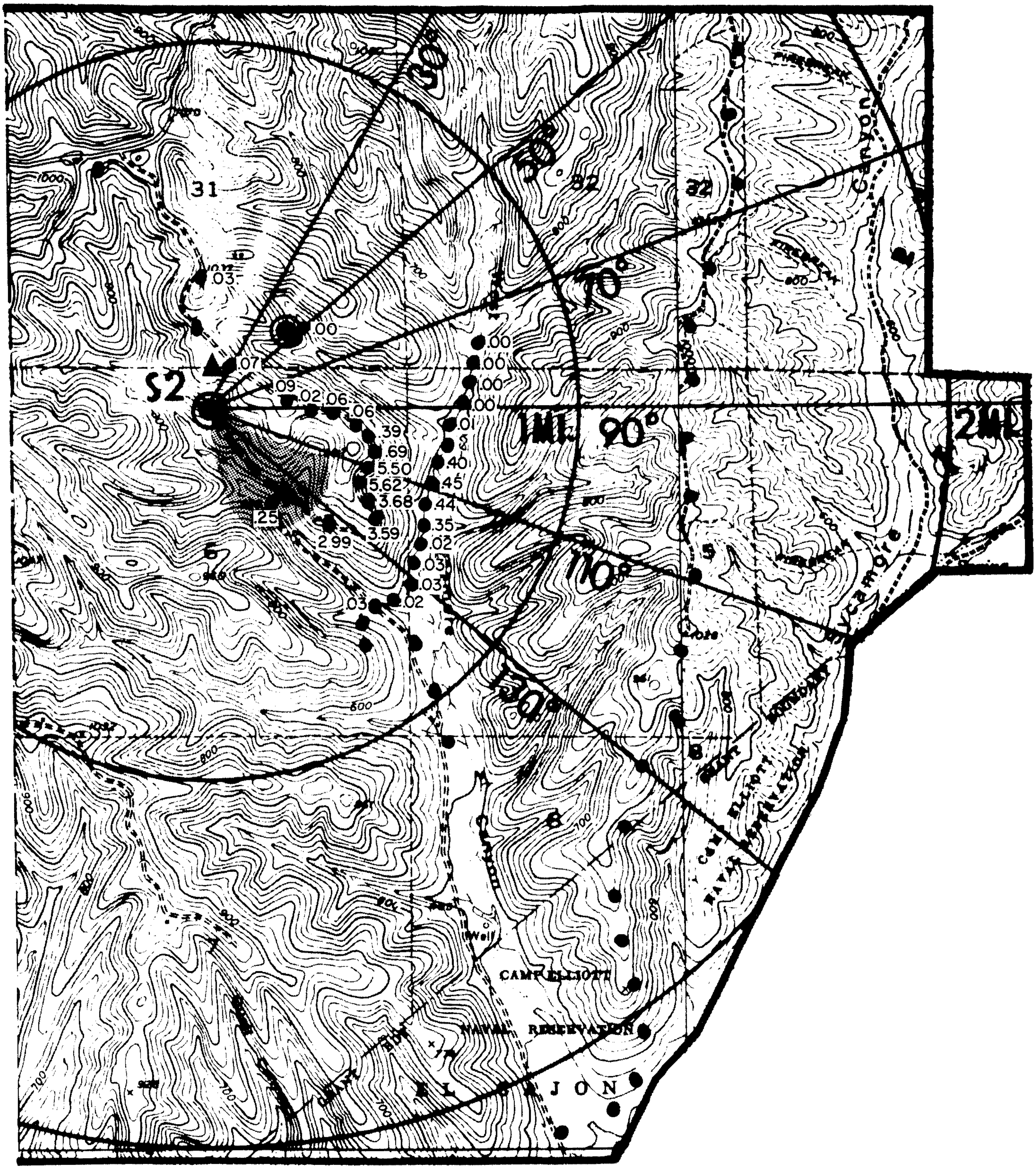


Trial: 4
Date: 28 April 1965
FP Release (Y): 1405-1406.5 PDT
Dosages: ppm-min for 100 lbs F_2

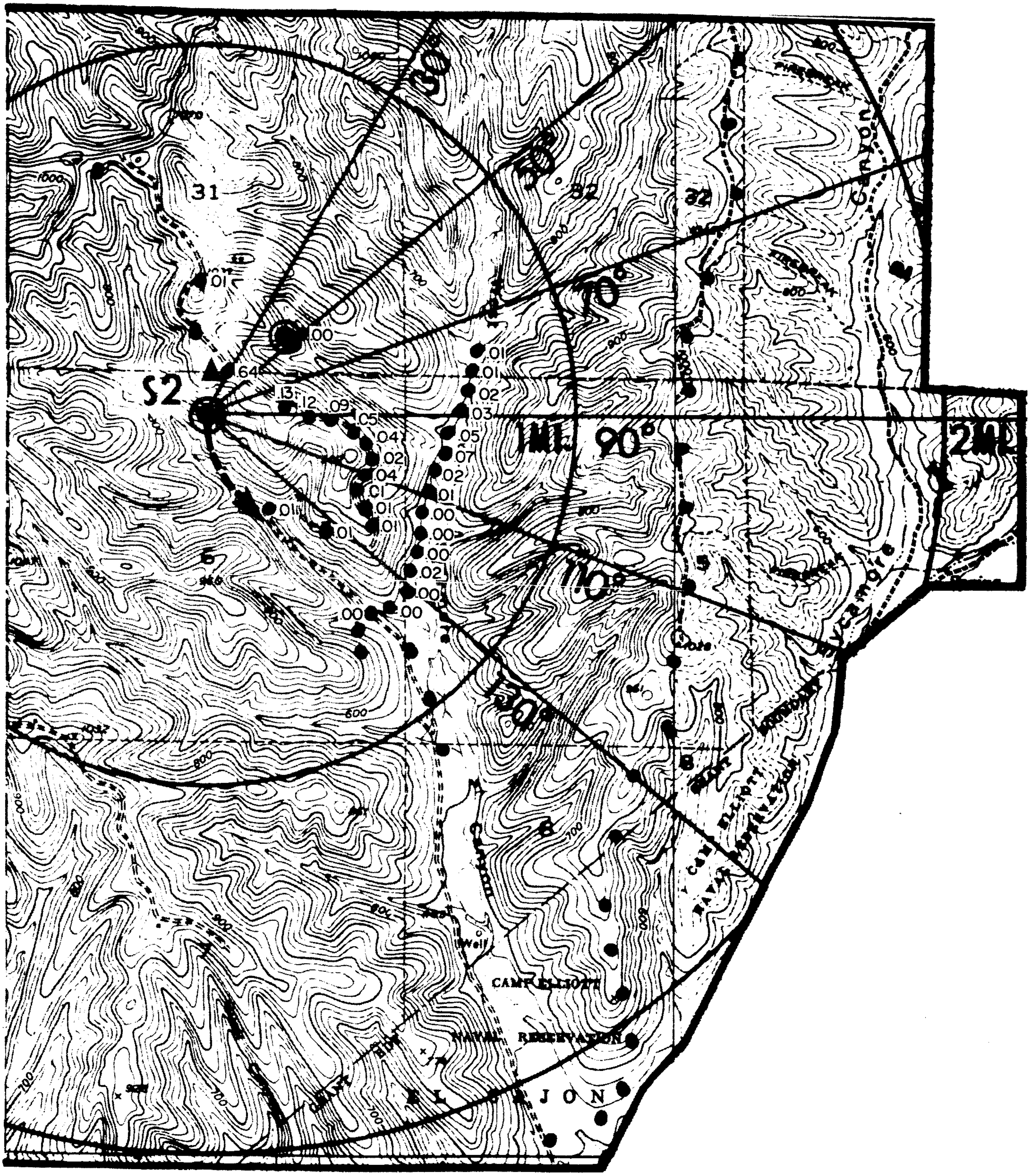


Trial: 5
Date: 28 April 1965
FP Release (Y): 1603-1604.5 PDT
Dosages: ppm-min for 100 lbs F_2

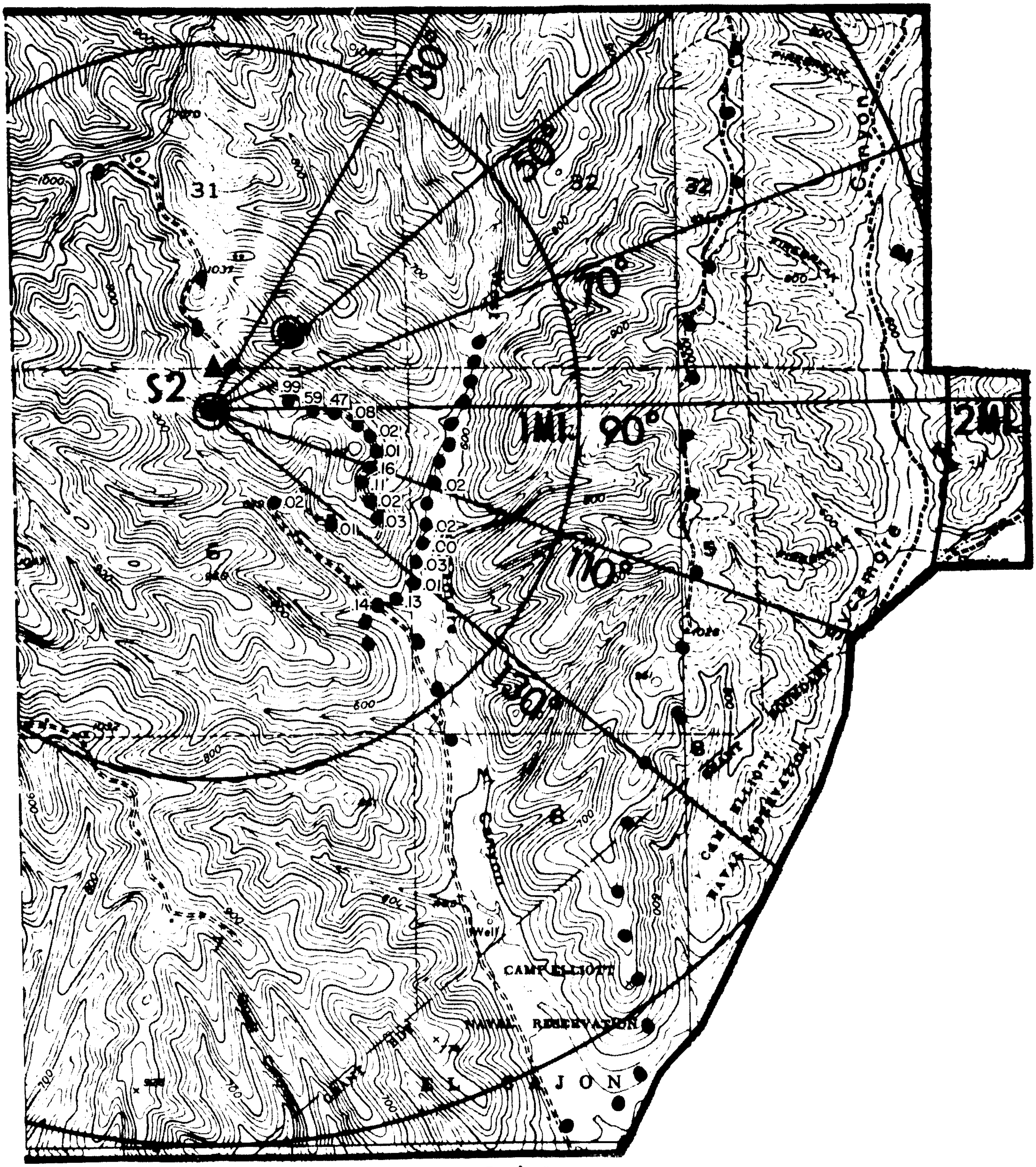
FP DOSAGES



Trial: 6
Date: 29 April 1965
FP Release (Y): 1057-1058.5 PDT
Dosages: ppm-min for 100 lbs F_2

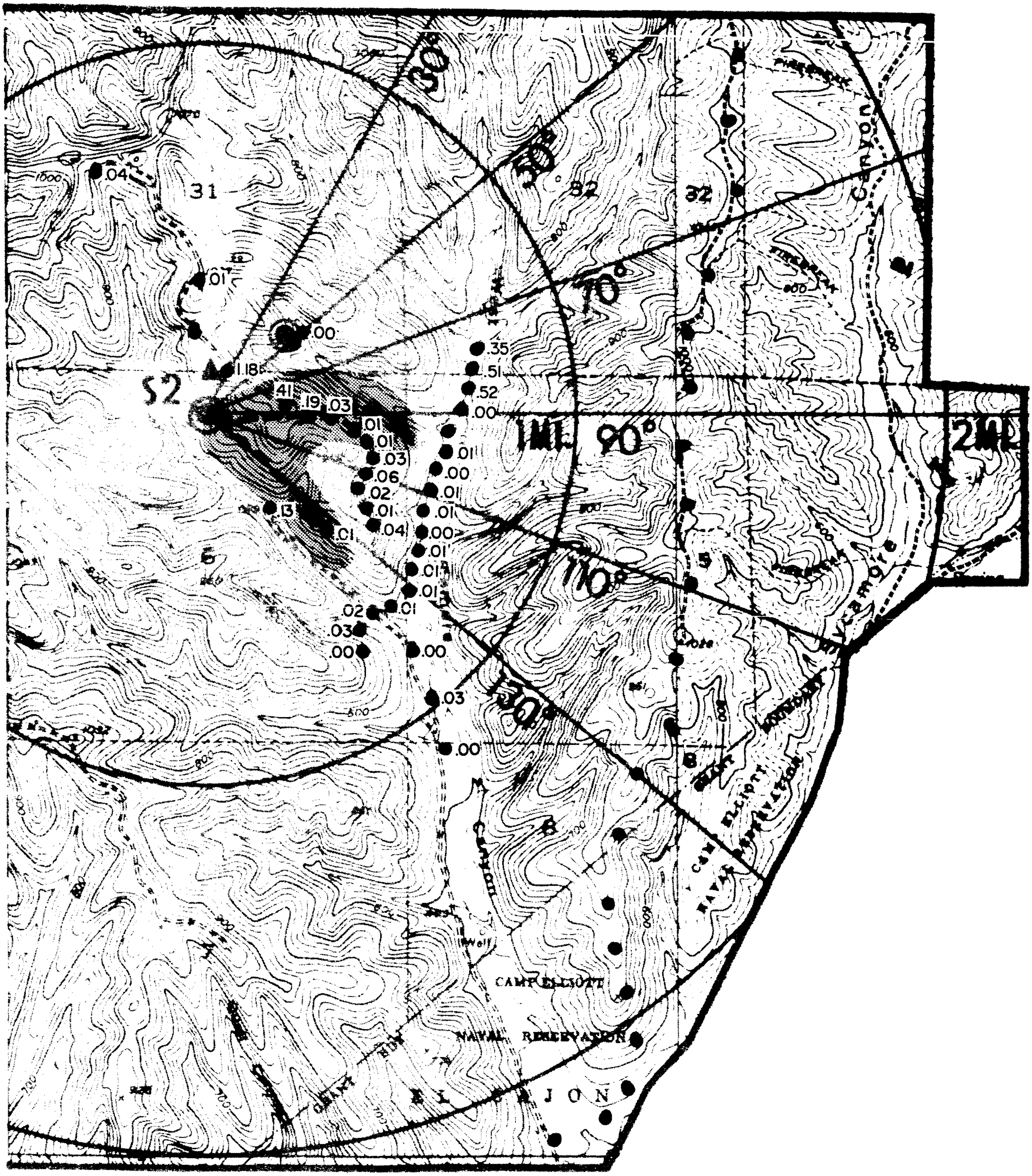


Trial: 7
Date: 29 April 1965
FP Release (Y): 1305-1306.5 PDT
Dosages: ppm-min for 100 lbs F_2

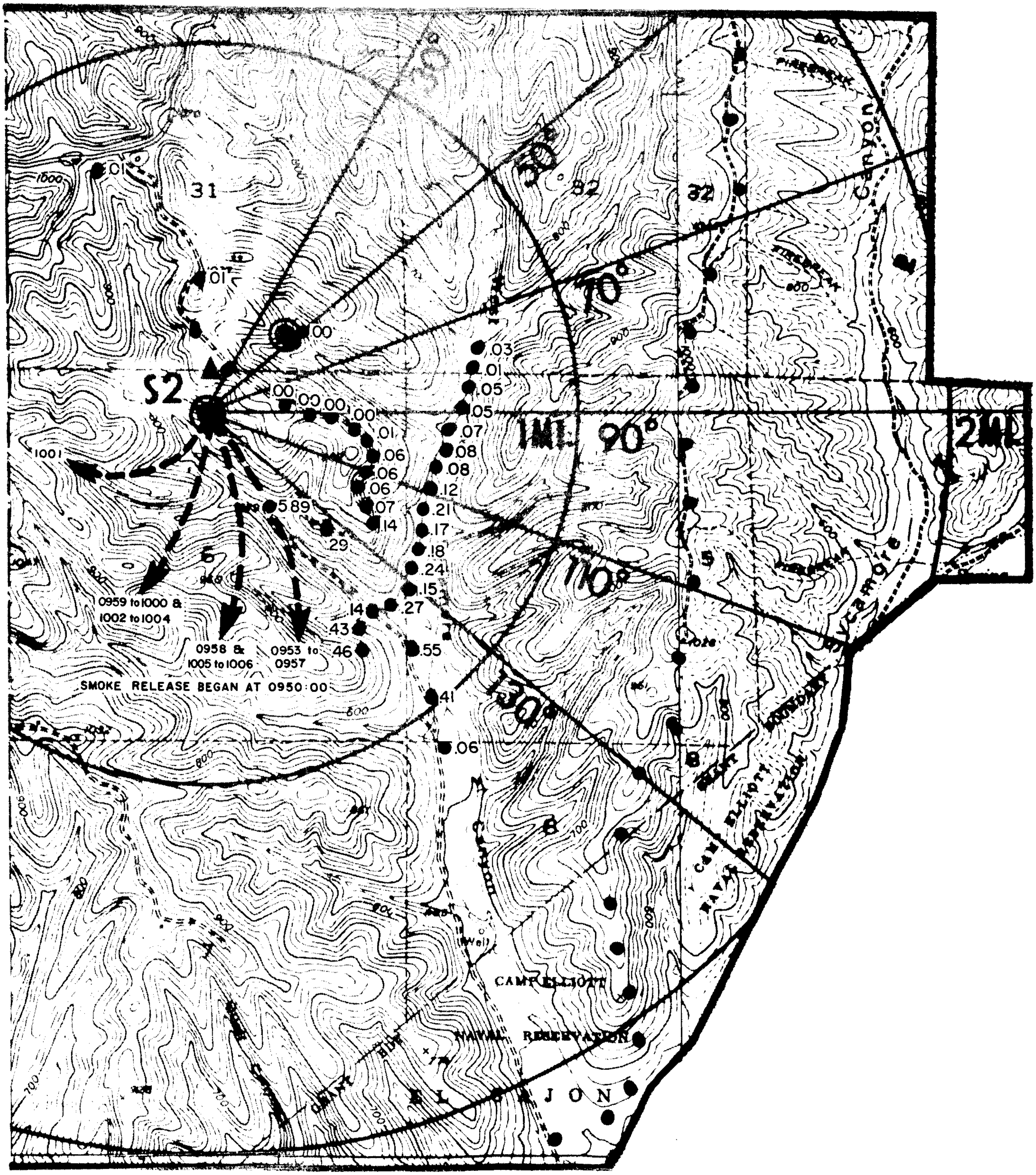


Trial: 8
Date: 8 June 1965
Start LO_2 Flow: 1426 PDT
FP Release (Y): 1450-1451.5
Dosages: ppm-min for 100 lbs F_2

FP DOSAGES

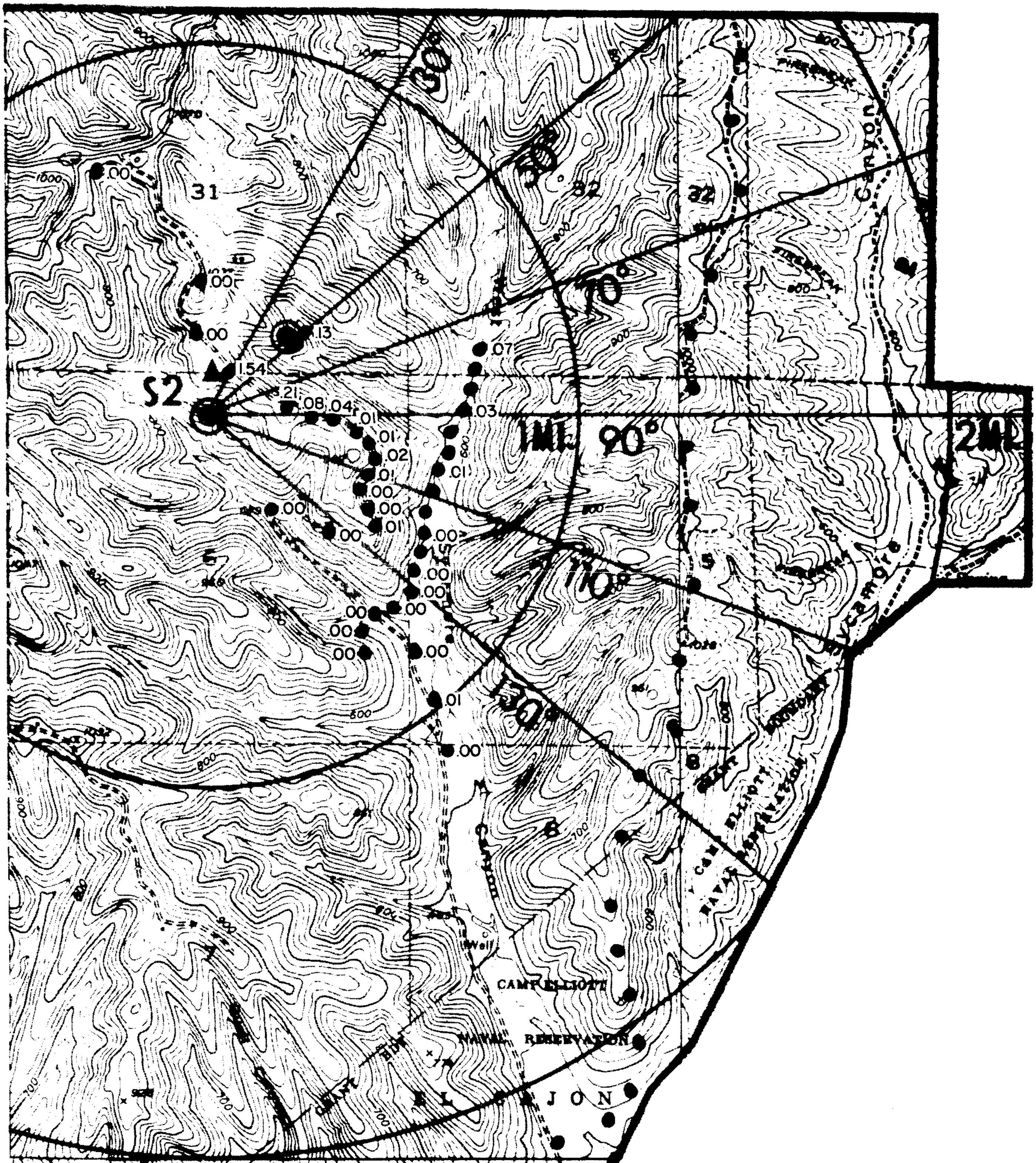


Trial: 9
Date: 9 June 1965
Start LO_2 Flow: 1226 PDT
FP Release (Y): 1310-1311.5
Dosages: ppm-min for 100 lbs F_2

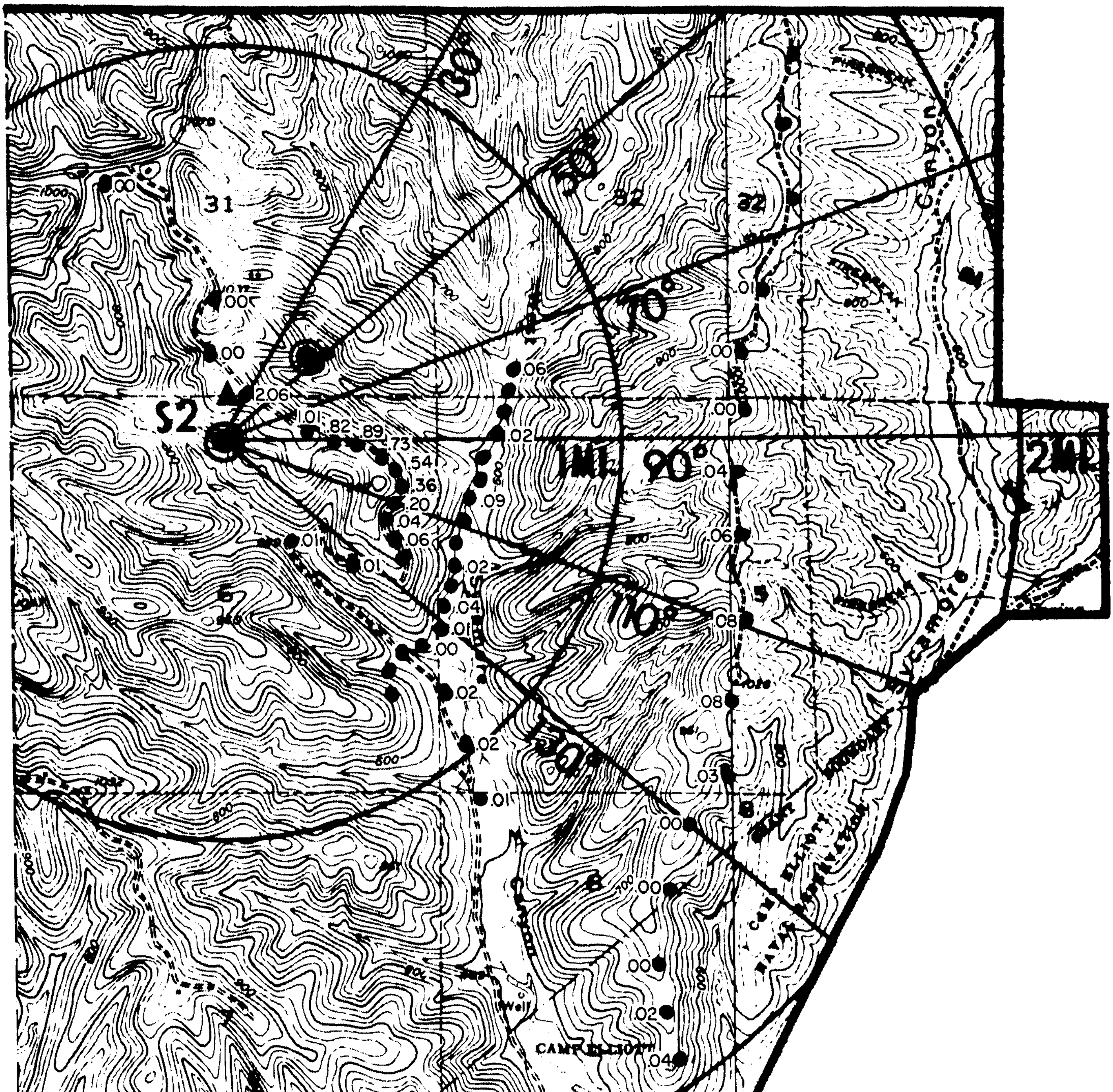


Trial: 10
Date: 11 June 1965
Start LO_2 Flow: 0930 PDT
FP Release (Y): 0950-0951.5
Dosages: ppm-min for 100 lbs F_2

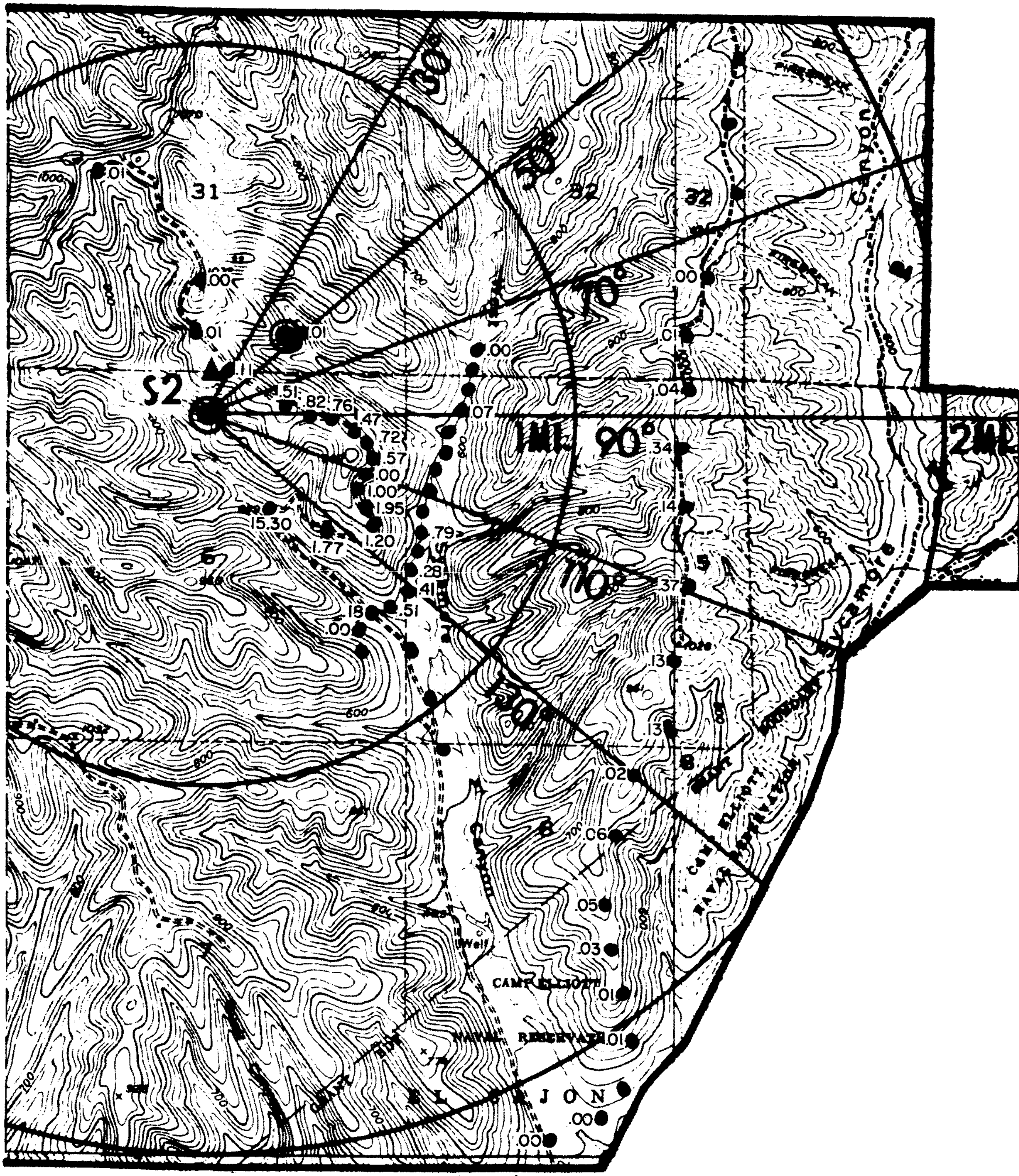
FP DOSAGES



Trial: 11
Date: 14 June 1965
Start LO_2 Flow: 1415 PDT
FP Release (Y): 1459-1469
Dosages: ppm-min for 100 lbs F_2

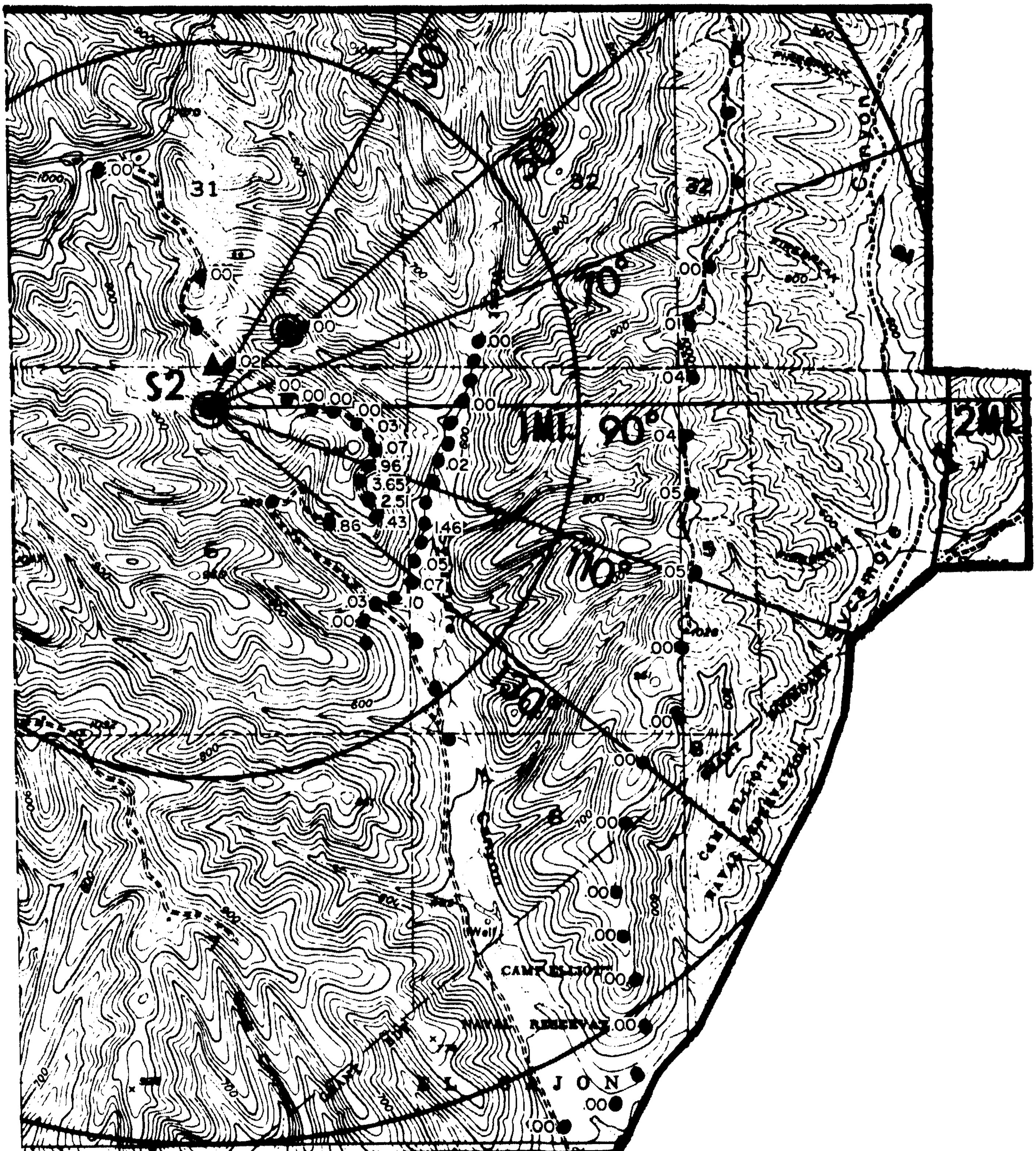


Trial: 12
Date: 17 June 1965
Start LO_2 Flow: 0939 PDT
FP Release (Y): 1009-1019
Dosages: ppm-min for 100 lbs F_2

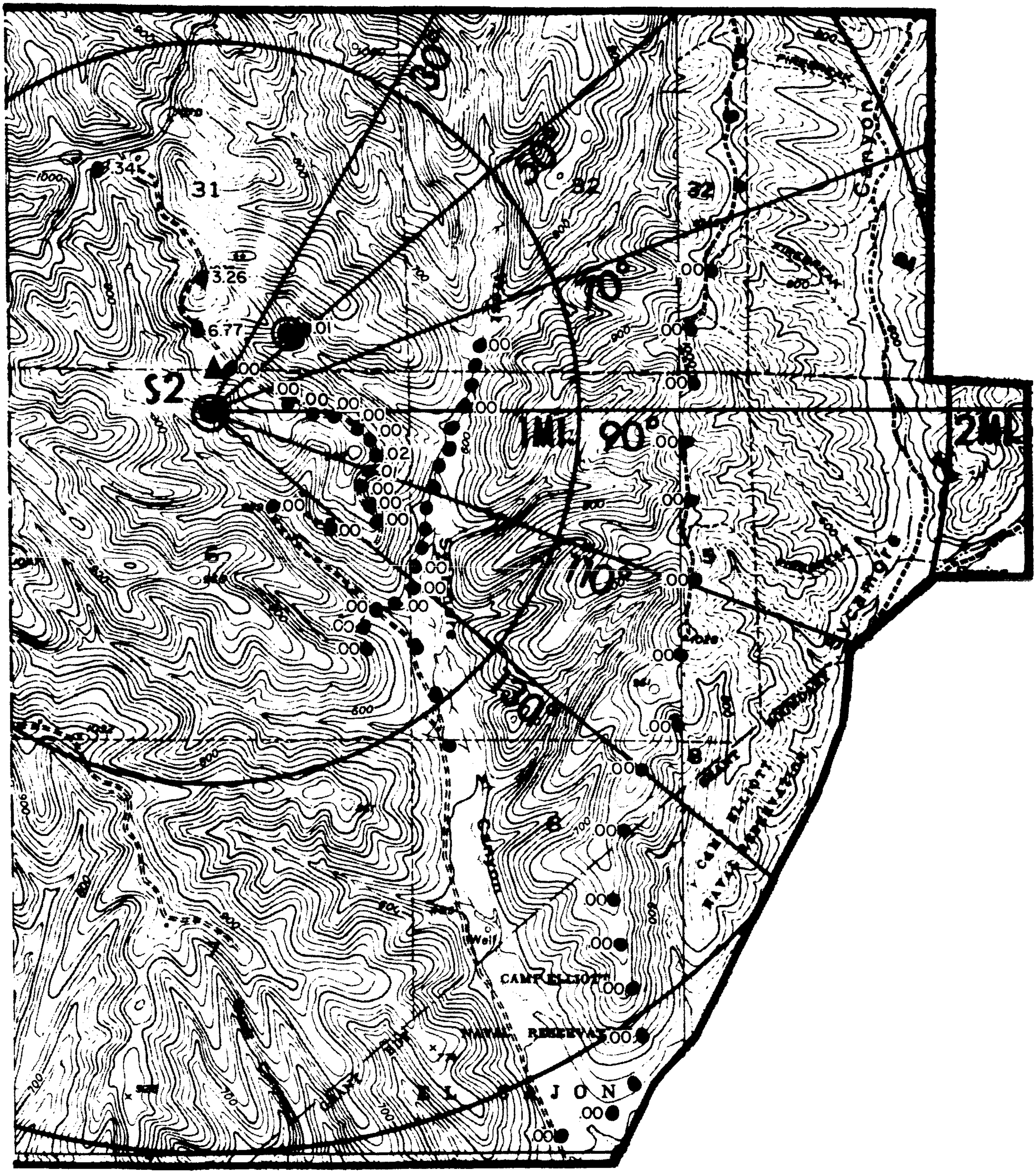


Trial: 13
Date: 24 June 1965
Start LF_2/LO_2 Flow: 1158 PDT
FP Release (Y): 1220-1228
Dosages: ppm-min for 100 lbs LF_2

FP DOSAGES

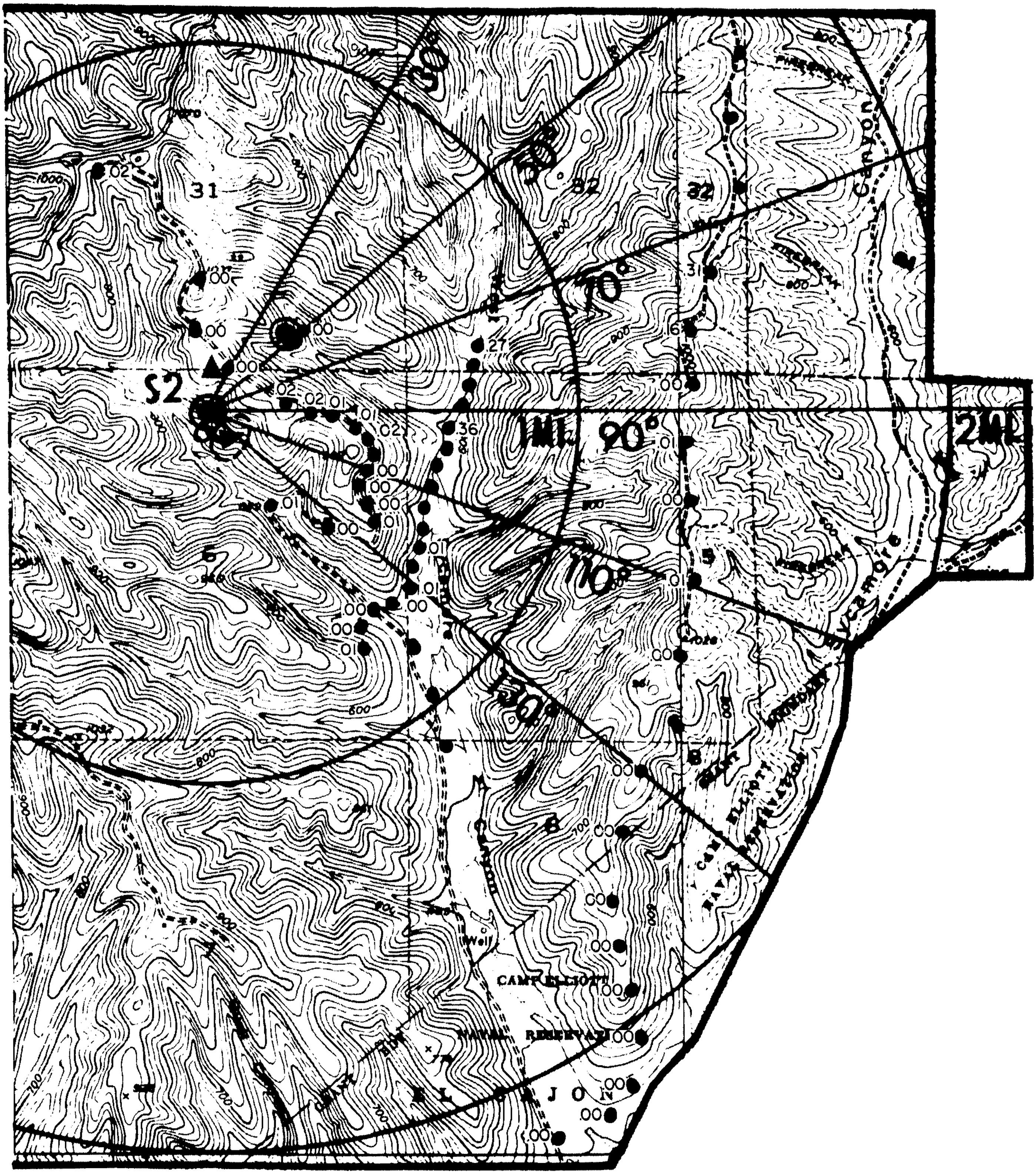


Trial: 14
Date: 24 June 1965
Start LF_2/LO_2 Flow: 1625 PDT
FP Release (Y): 1643-1650
Dosages: ppm-min for 100 lbs F_2



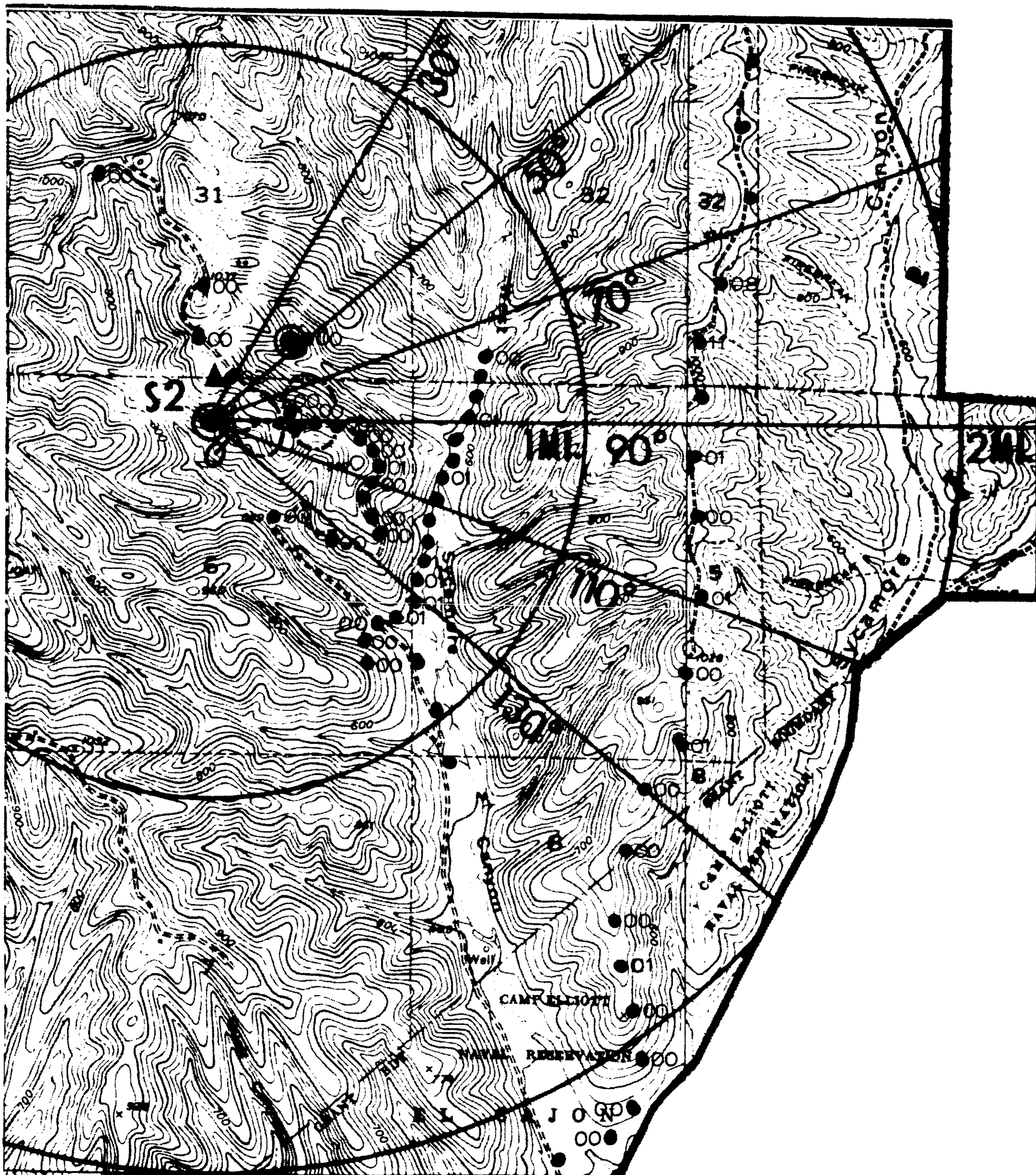
Trial: 15
Date: 25 June 1965
FP Release (Y): 1335-1345
Dosages: ppm-min for 100 lbs F_2

FP DOSAGES

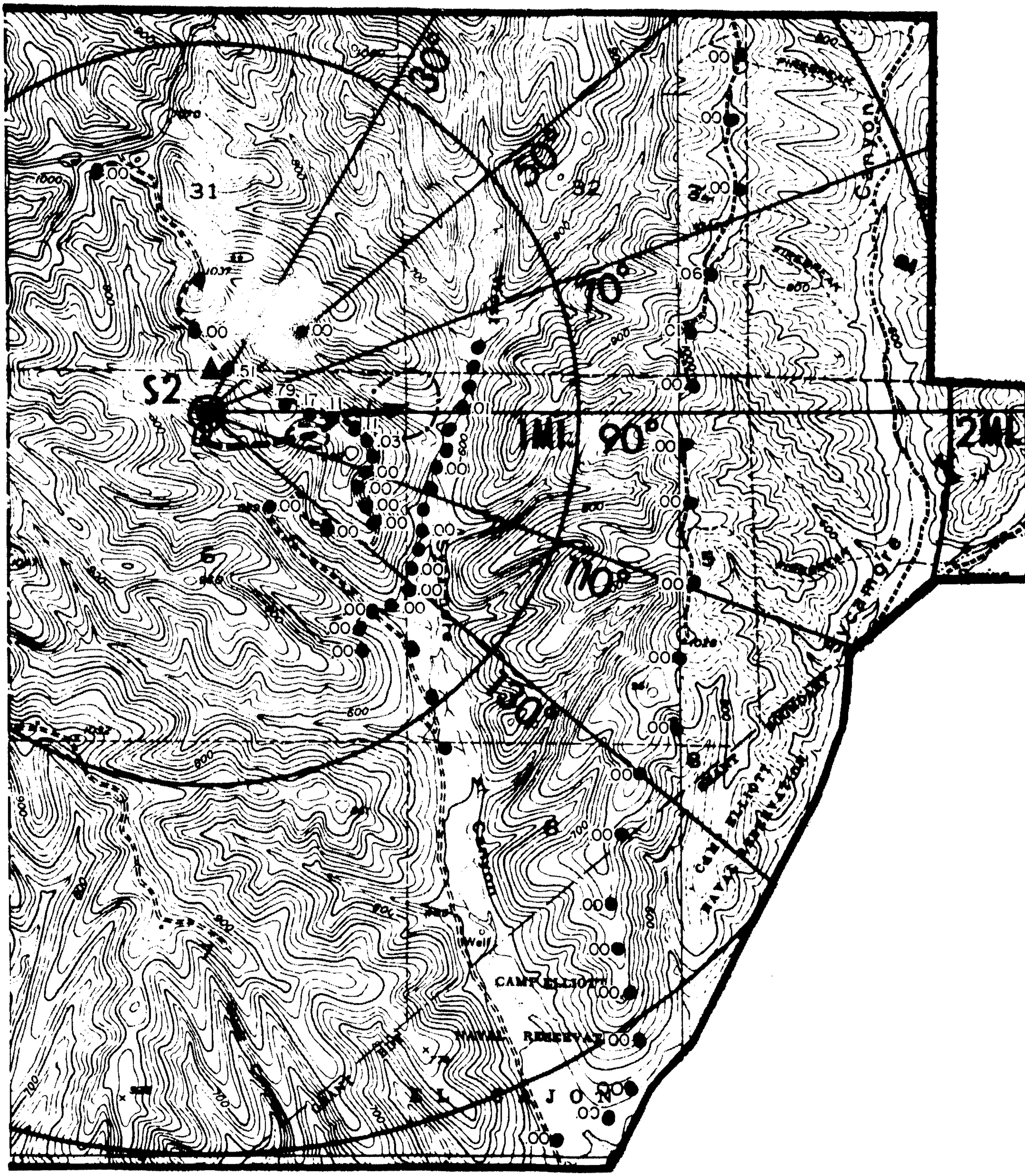


Trial: 19
Date: 8 July 1965
LF_2/LO_2 Ignition Time: 1340 PDT
FP Release (Y): 1339:53-1340:08
Dosages: ppm-min for 100 lbs F_2

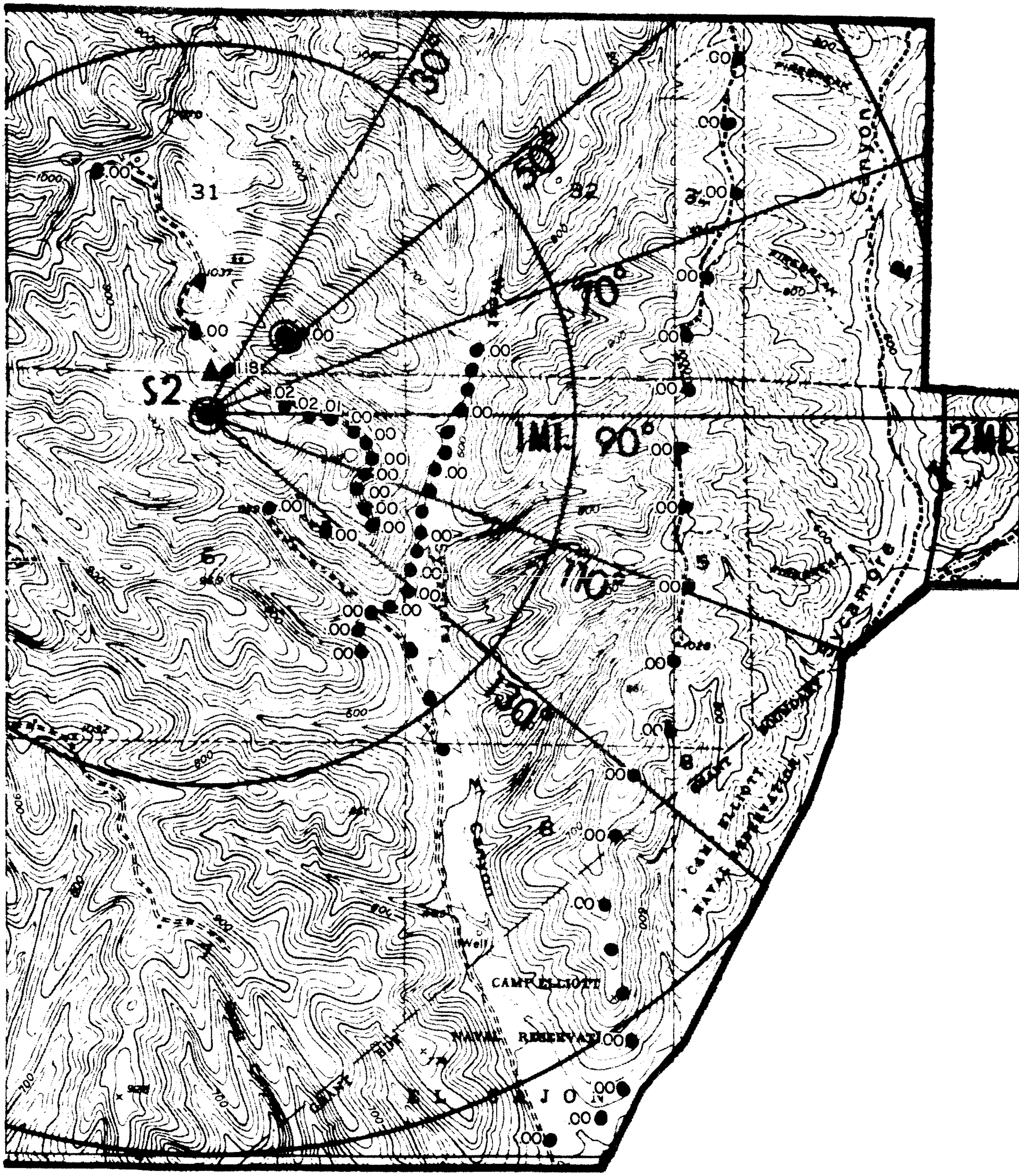
FP DOSAGES



Trial: 20
Date: 12 July 1965
LF_2/LO_2 Ignition Time: 1529 PDT
FP Release (Y): 1528:50-1529:05
Dosages: ppm-min for 100 lbs F_2



Trial: 21
Date: 19 July 1965
LF_2/LO_2 Ignition Time: 1500 PDT
FP Release (Y): 1459:50-1500:05
Dosages: ppm-min for 100 lbs F_2



Trial: 21
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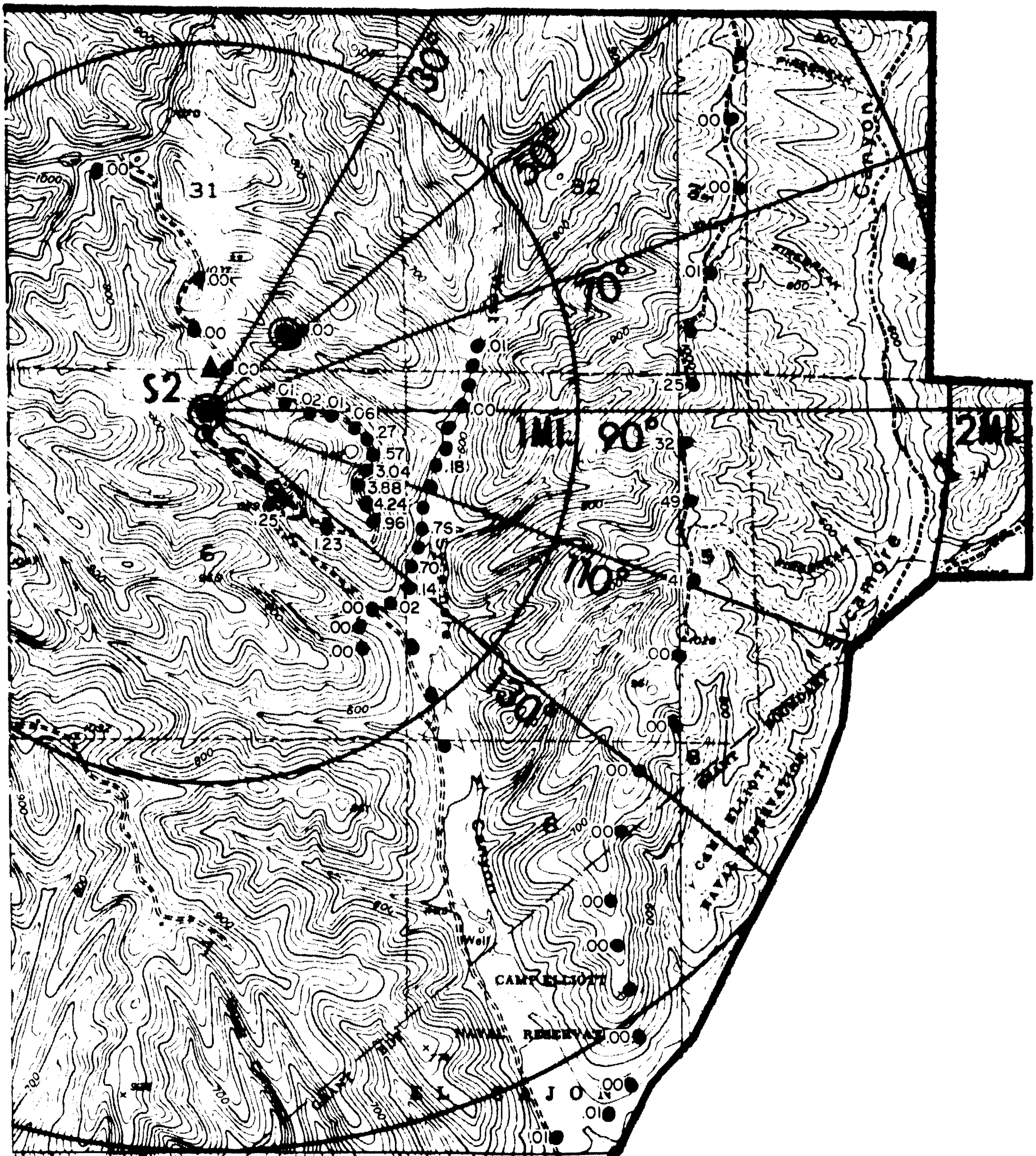
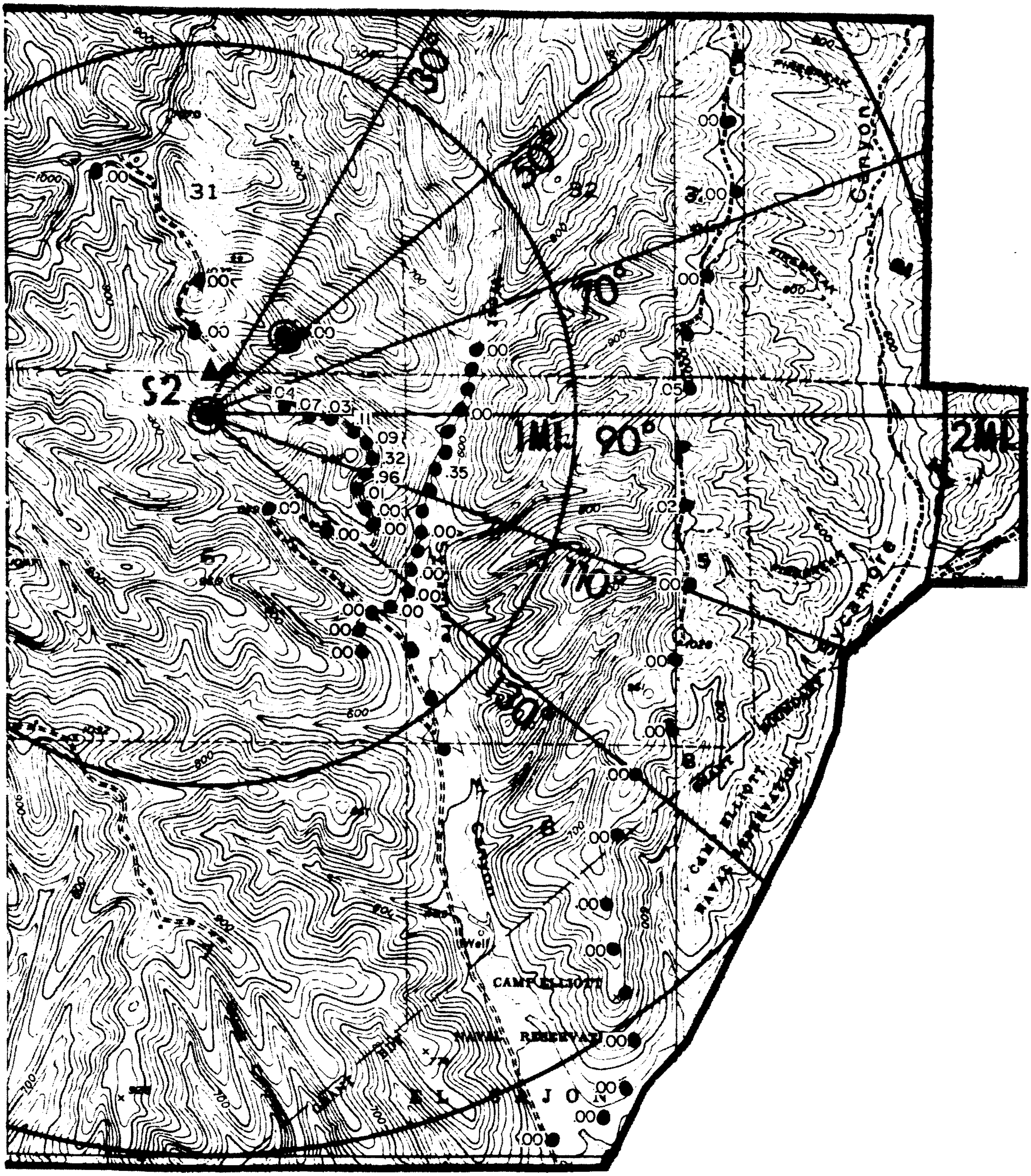
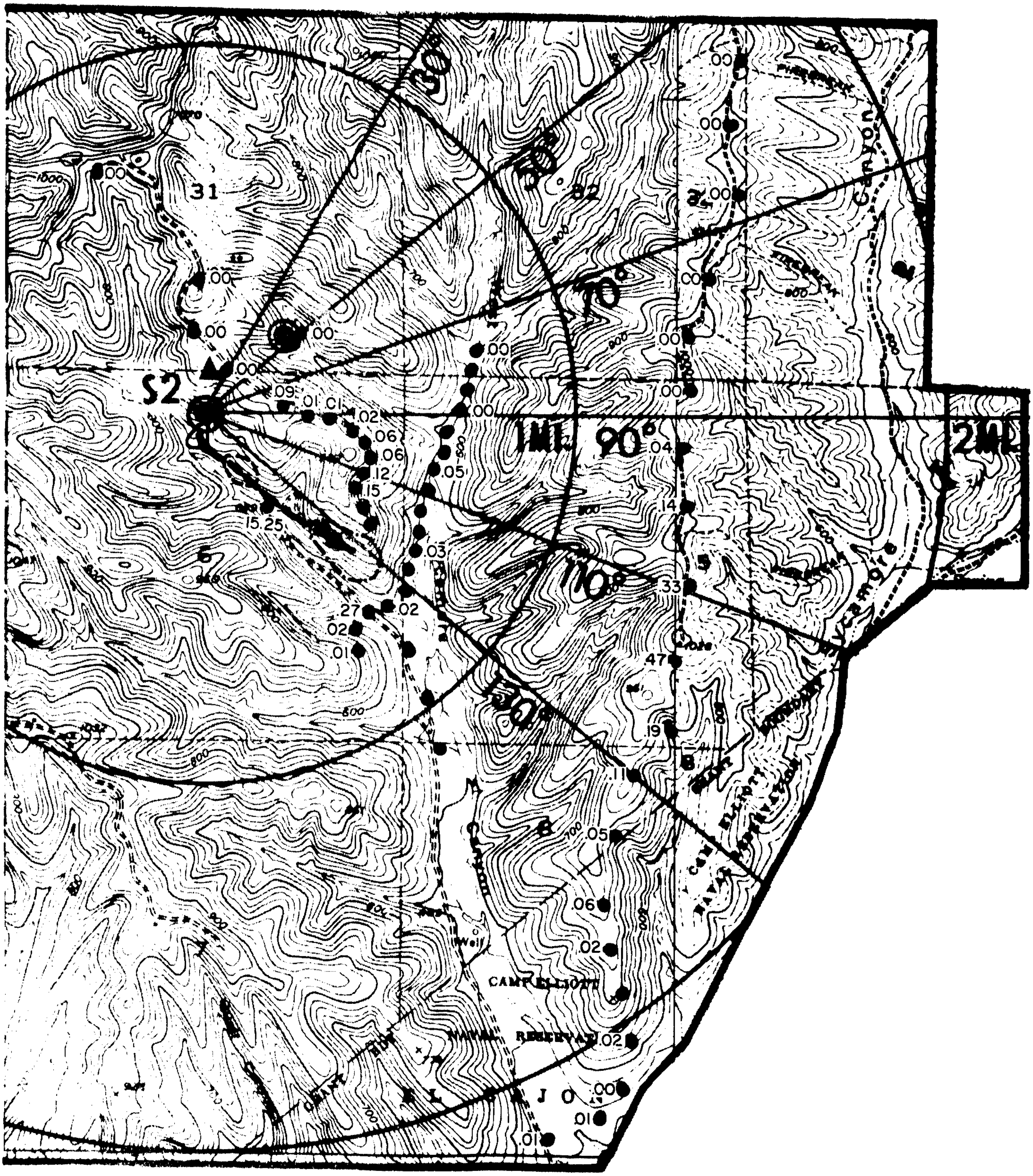
LF_2/LO_2 Ignition Time: 1500 PDT
FP Release (G): 1510:00-1510:15
Dosages: ppm-min for 100 lbs F_2



Trial: 22
Date: 21 July 1965
LF_2/LO_2 Ignition Time: 1303 PDT
FP Release (Y): 1302:50-1303:05
Dosages: ppm-min for 100 lbs F_2

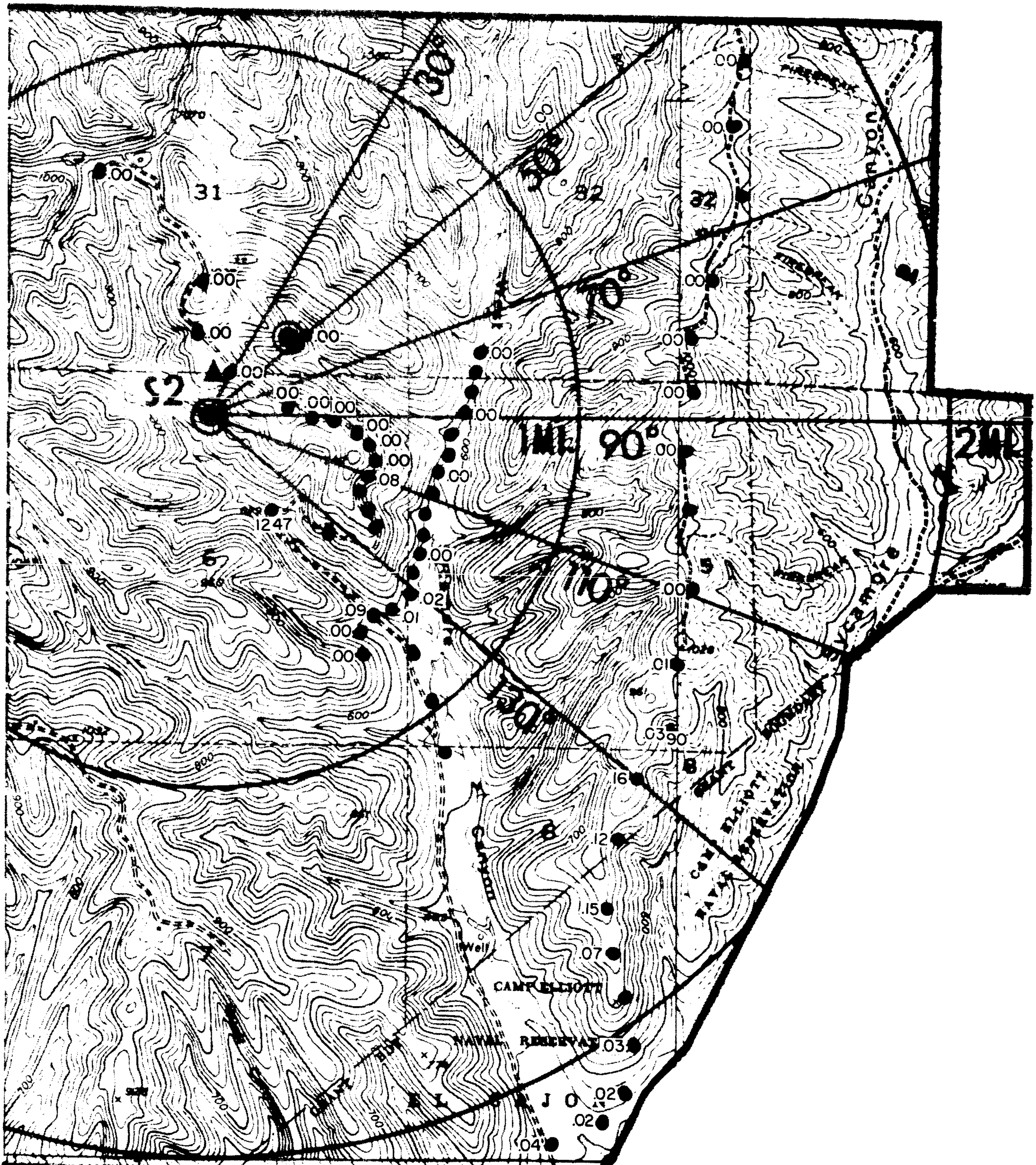


Trial: 22
Date: 21 July 1965
LF_2/LO_2 Ignition Time: 1303 PDT
FP Release (G): 1316:00-1316:15
Dosages: ppm-min for 100 lbs F_2



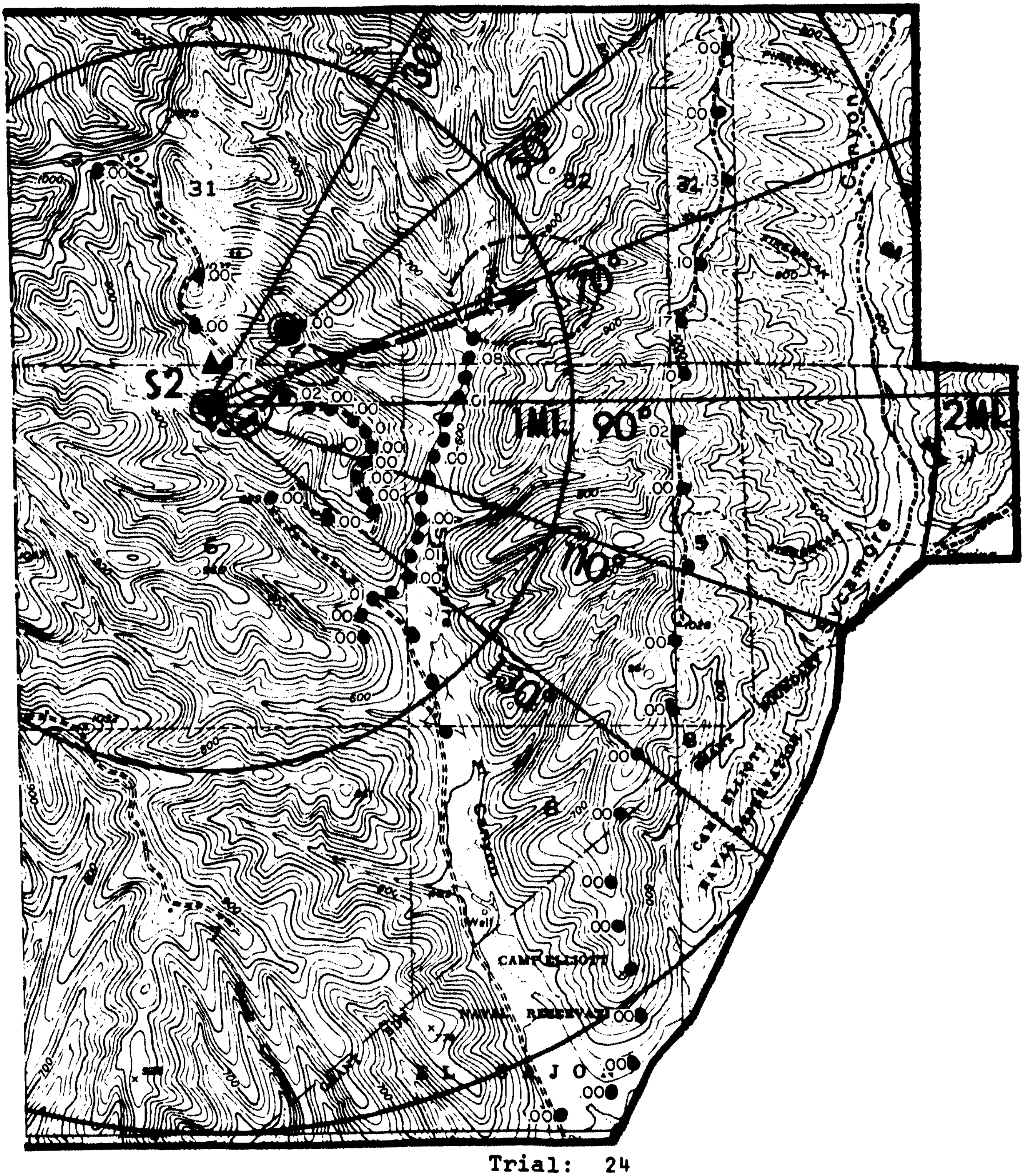
Trial: 23
Date: 27 July 1965
LF_2/LO_2 Ignition Time: 1019 PDT
FP Release (Y): 1018:50-1019:05
Dosages: ppm-min for 100 lbs F_2

FP DOSAGES



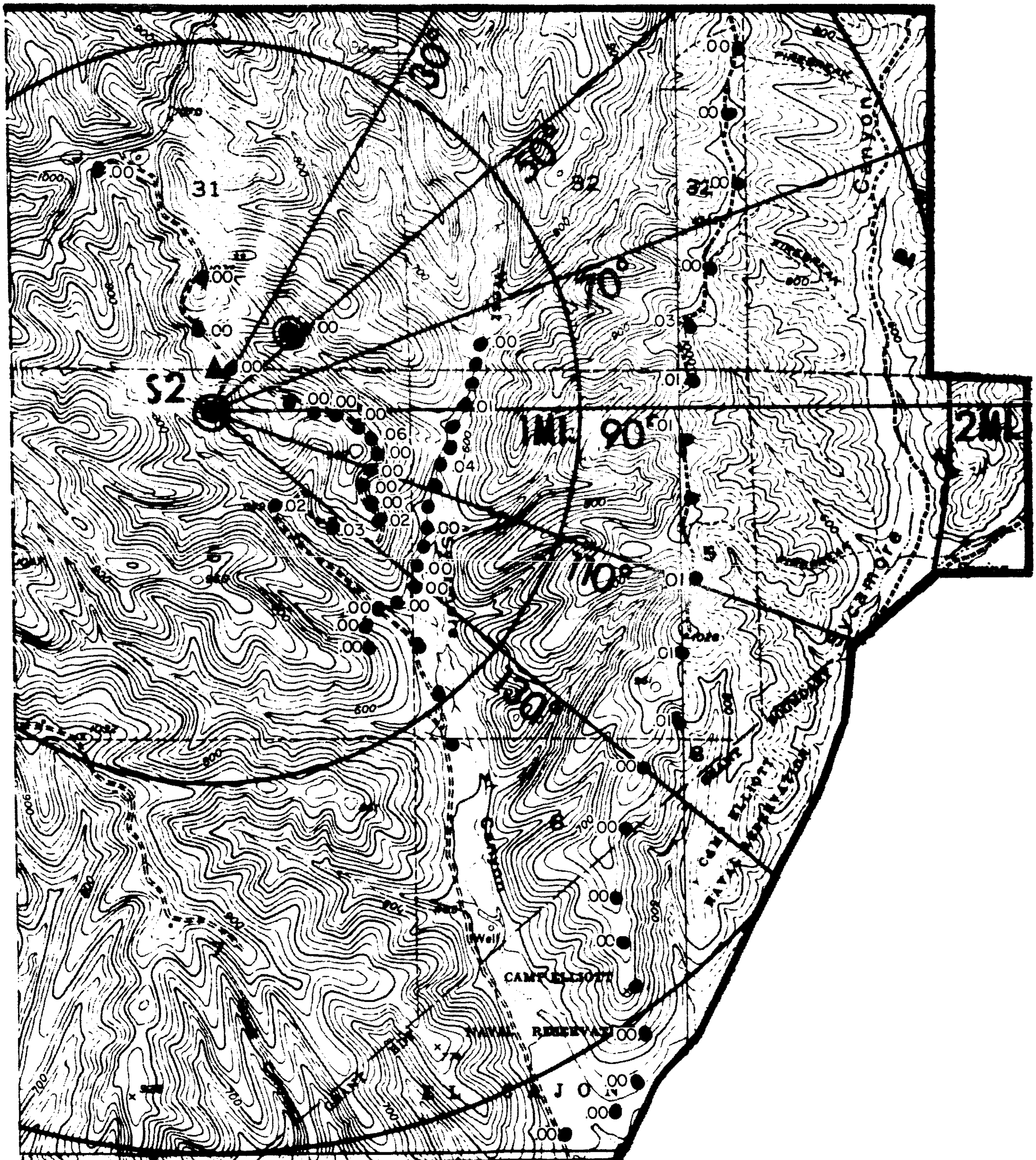
Trial: 23
Date: 27 July 1965
LF_2/LO_2 Ignition Time: 1019 PDT
FP Release (G): 1030:00-1030:15
Dosages: ppm-min for 100 lbs F_2

FP DOSAGES

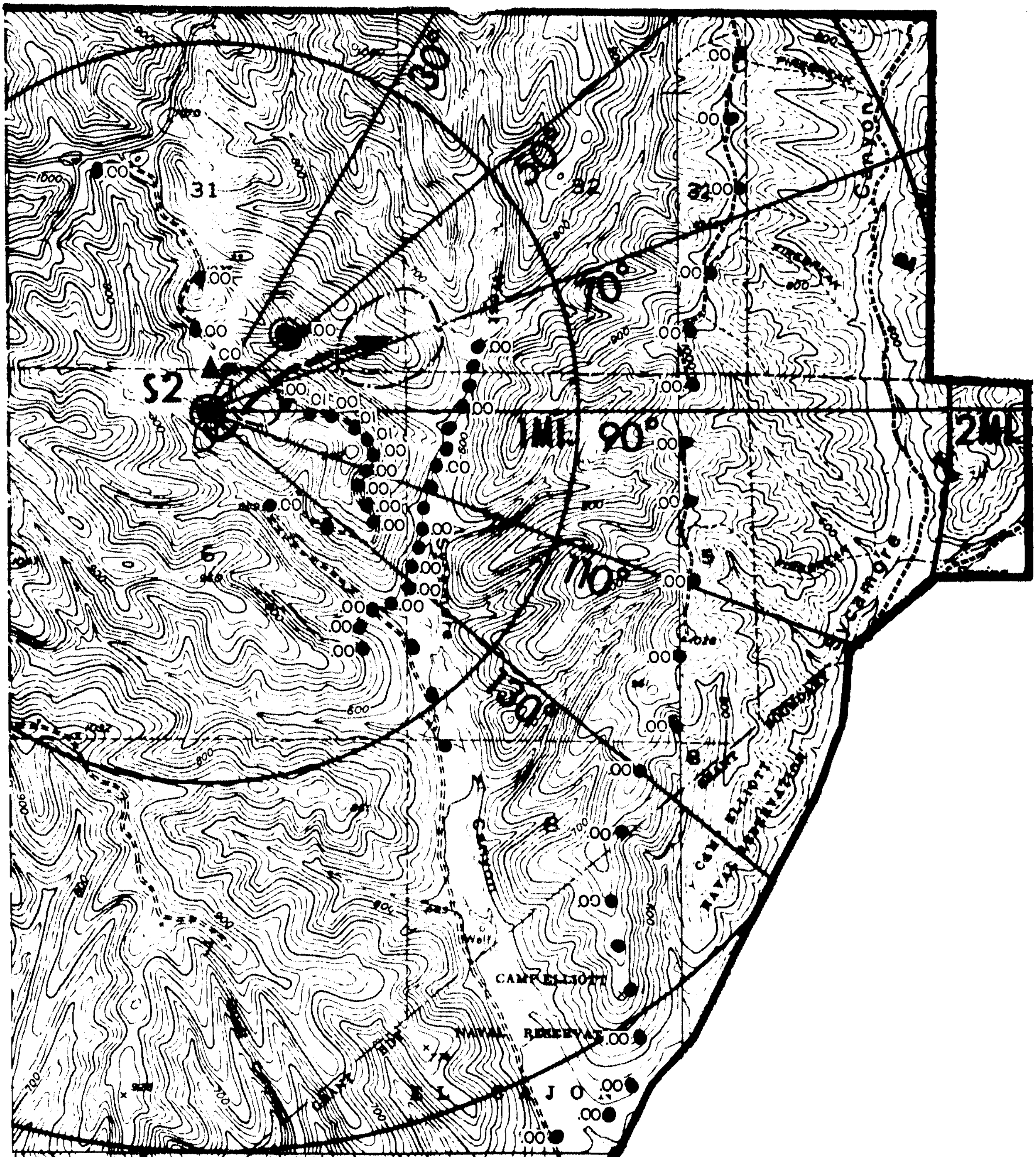


Trial: 24
Date: 30 July 1965
LF_2/LO_2 Ignition Time: 1337 PDT
FP Release (Y): 1336:53-1337:08
Dosages: ppm-min for 100 lbs F_2

FP DOSAGES

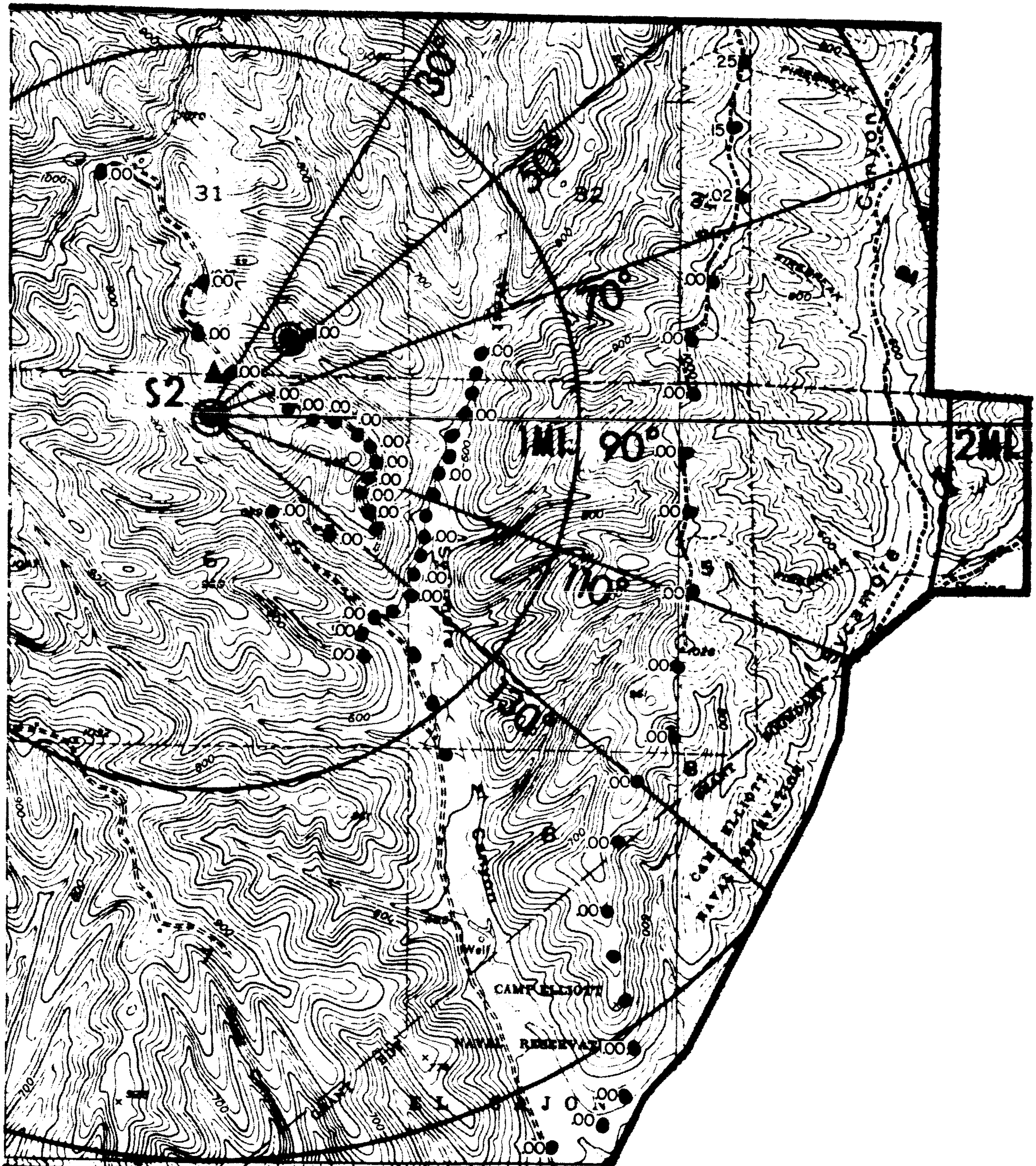


Trial: 24
Date: 30 July 1965
LF_2/LO_2 Ignition Time: 1337 PDT
FP Release (G): 1347:00-1347:15
Dosages: ppm-min for 100 lbs F_2



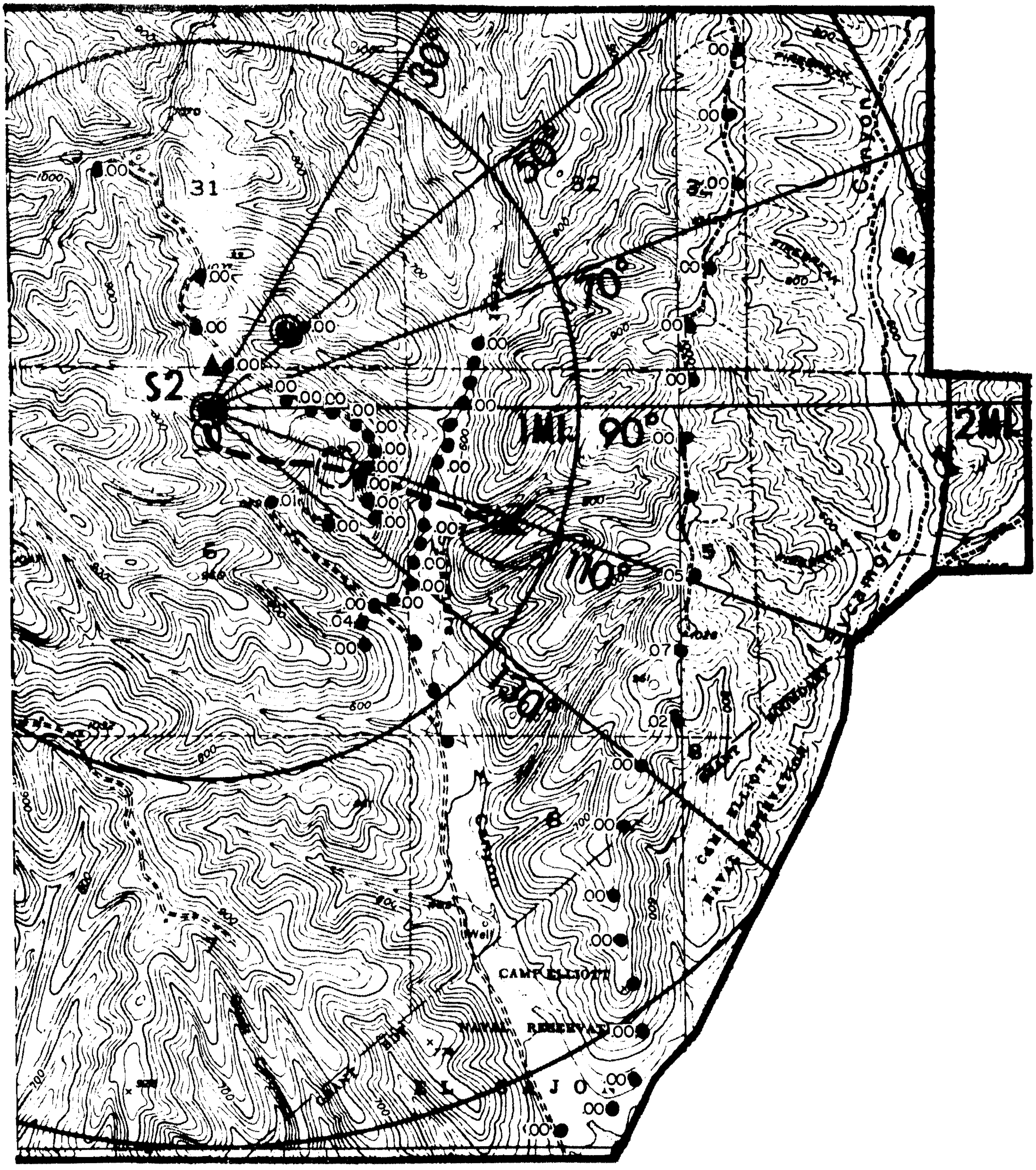
Trial: 25
Date: 4 August 1965
LF_2/LO_2 Ignition Time: 1304 PDT
FP Release (Y): 1304:02
Dosages: ppm-min for 100 lbs F_2

FP DOSAGES



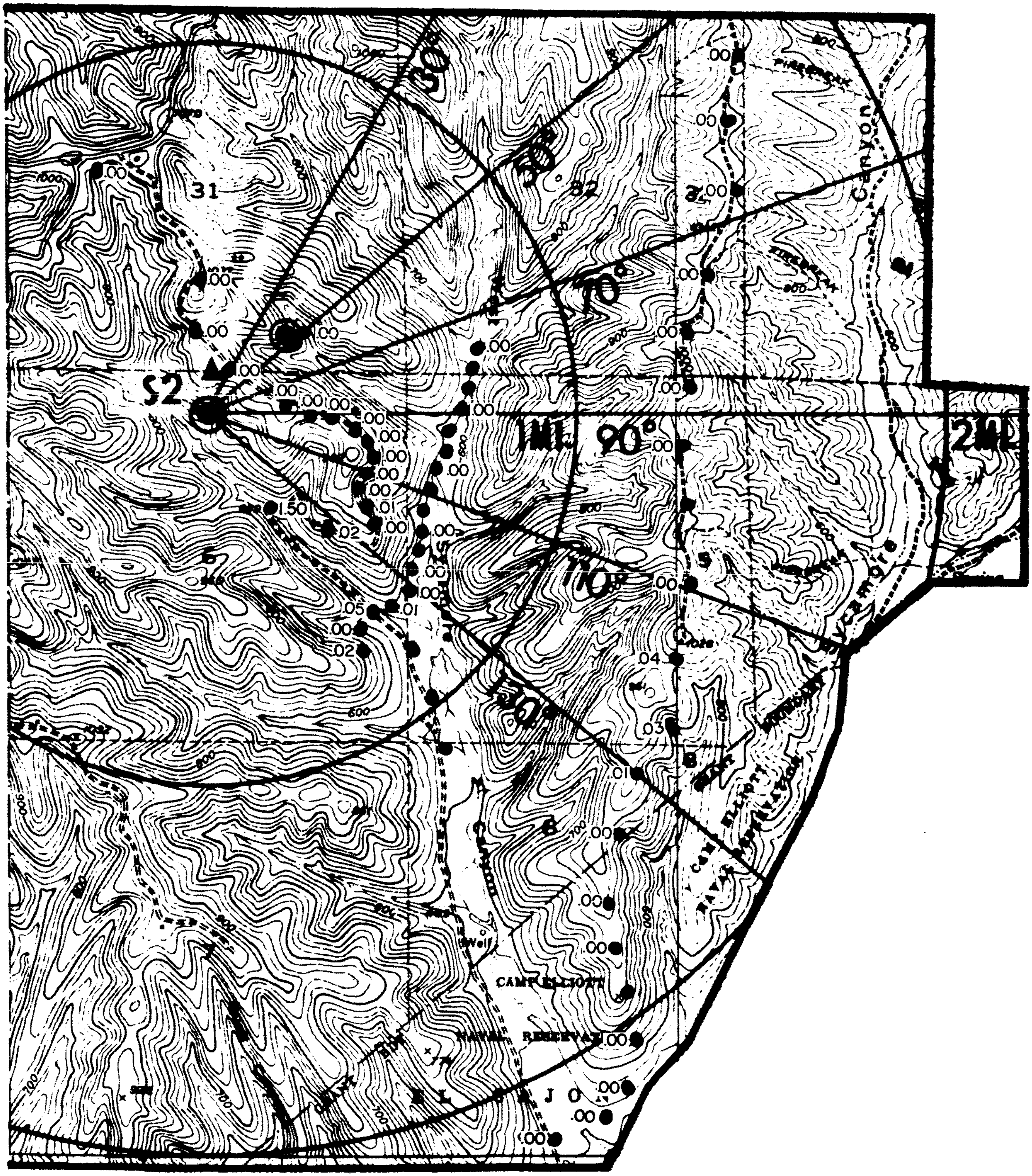
Trial: 25
Date: 4 August 1965
LF_2/LO_2 Ignition Time: 1304 PDT
FP Release (G): 1302:00-1302:15
Dosages: ppm-min for 100 lbs F_2

FP DOSAGES

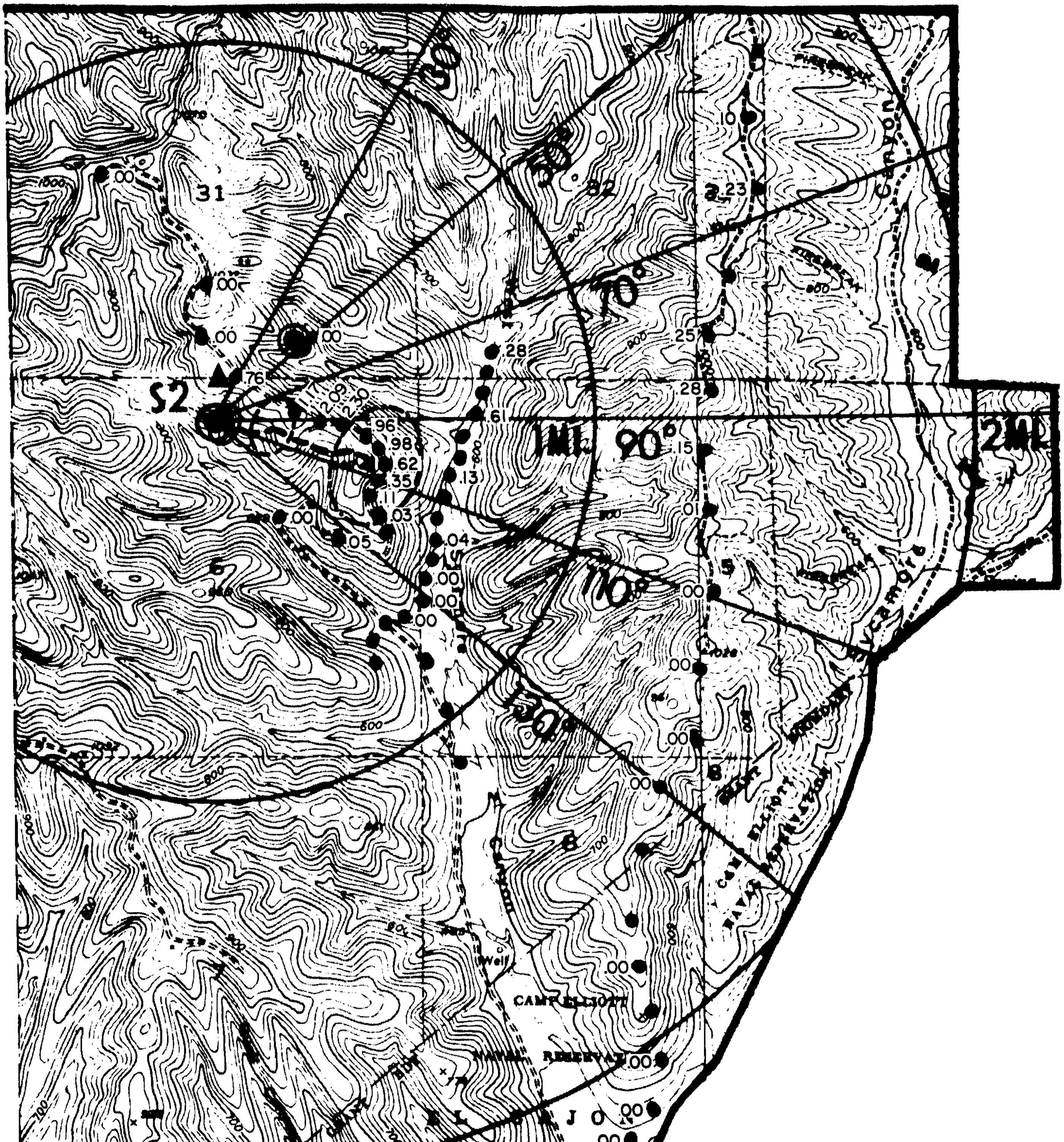


Trial: 26
Date: 9 August 1965
LF_2/LO_2 Ignition Time: 1033 PDT
FP Release (Y): 1033:04
Dosages: ppm-min for 100 lbs F_2

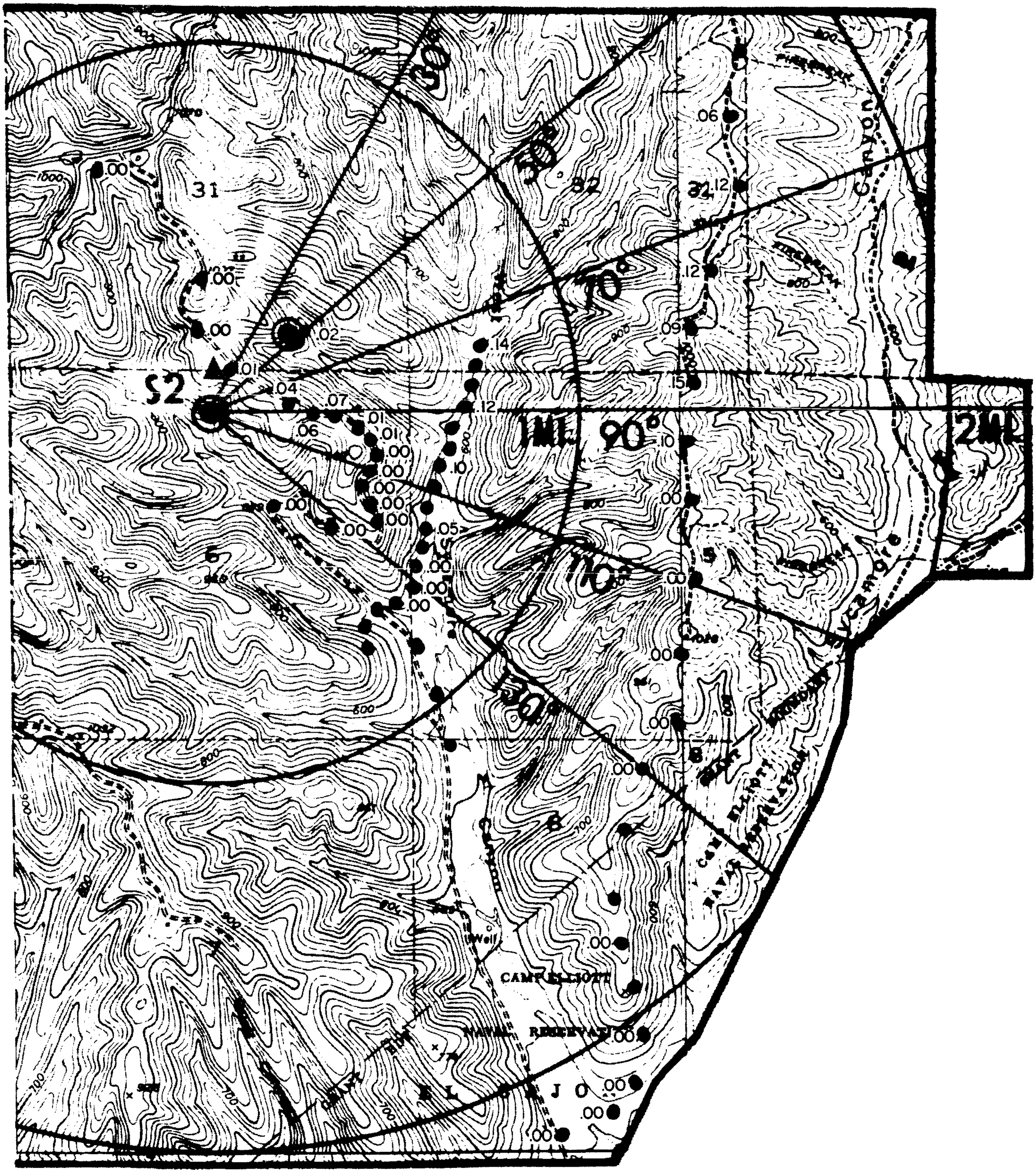
FP DOSAGES



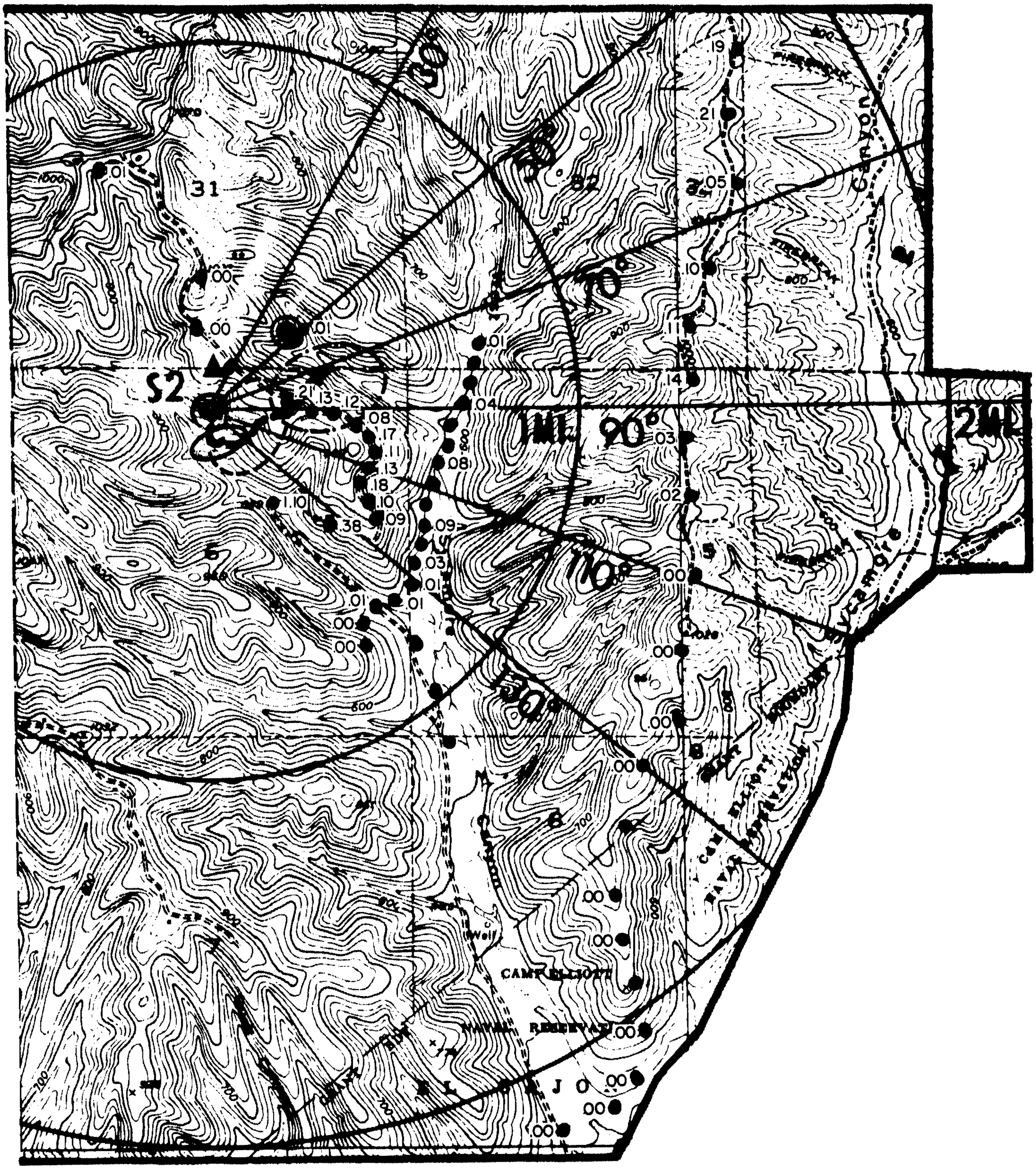
Trial: 26
Date: 9 August 1965
LF_2/LO_2 Ignition Time: 1033 PDT
FP Release (G): 1031:00-1031:15
Dosages: ppm-min for 100 lbs F_2



Trial: 27
Date: 31 August 1965
LF_2/LO_2 Ignition Time: 1006:30 PDT
FP Release (Y): 1006:34
Dosages: ppm-min for 100 lbs F_2

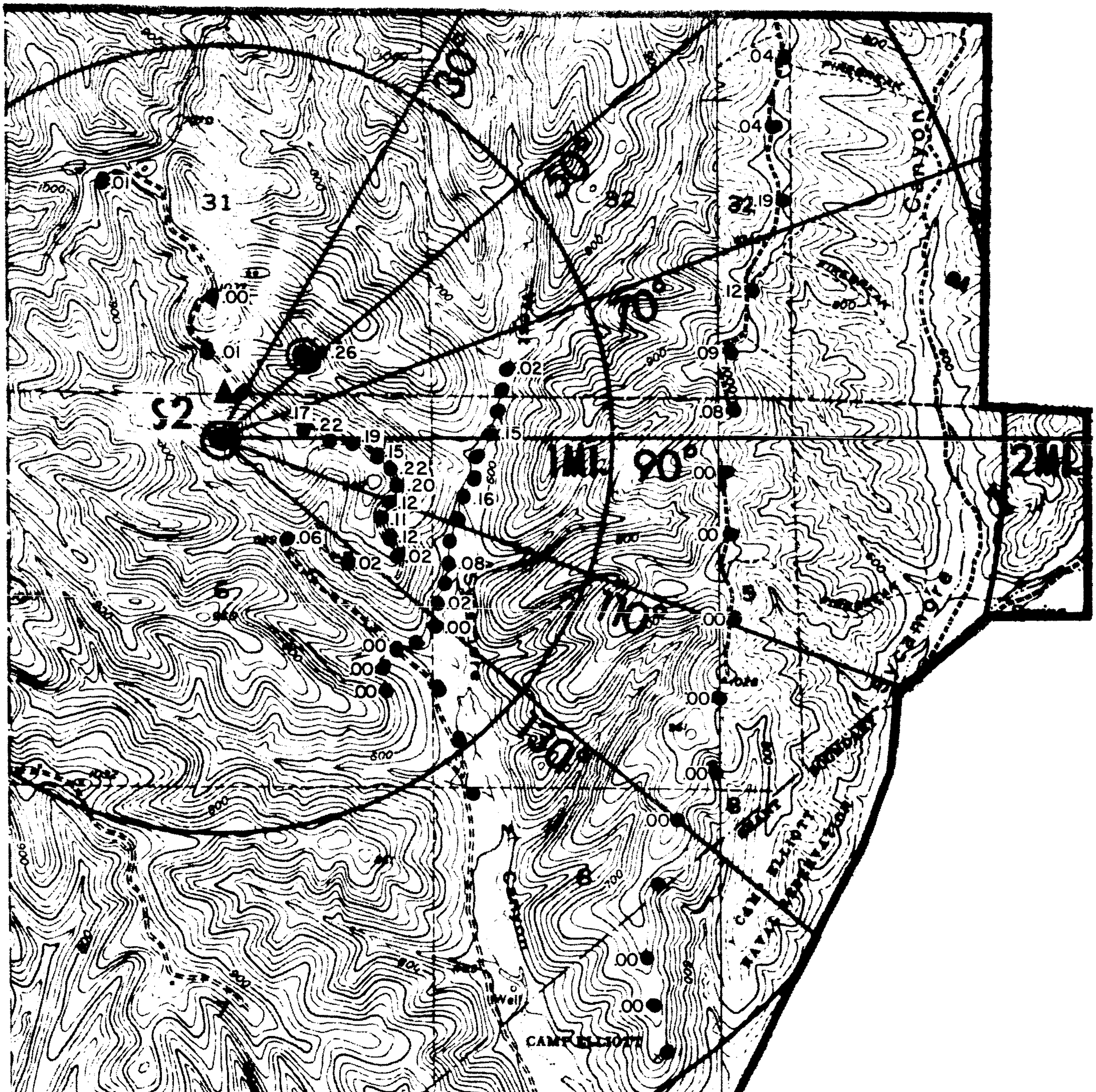


Trial: 27
Date: 31 August 1965
LF_2/LO_2 Ignition Time: 1006:30 PDT
FP Release (G): 1009:00-1009:15
Dosages: ppm-min for 100 lbs F_2



Trial: 28
Date: 3 September 1965
LF_2/LO_2 Ignition Time: 0942 PDT
FP Release (Y): 0940:00-0940:15
Dosages: ppm-min for 100 lbs F_2

FP DOSAGES



Trial: 28
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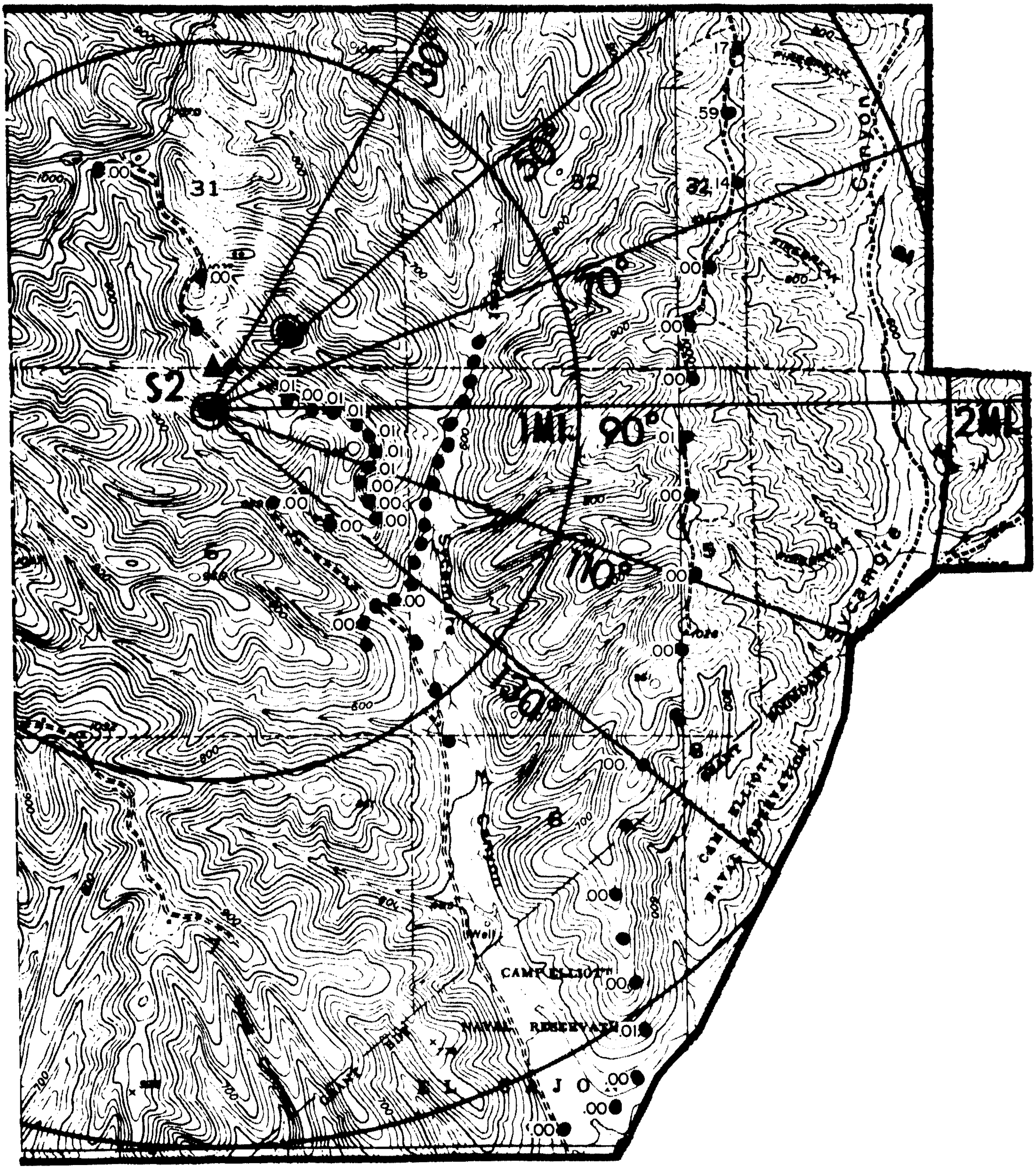
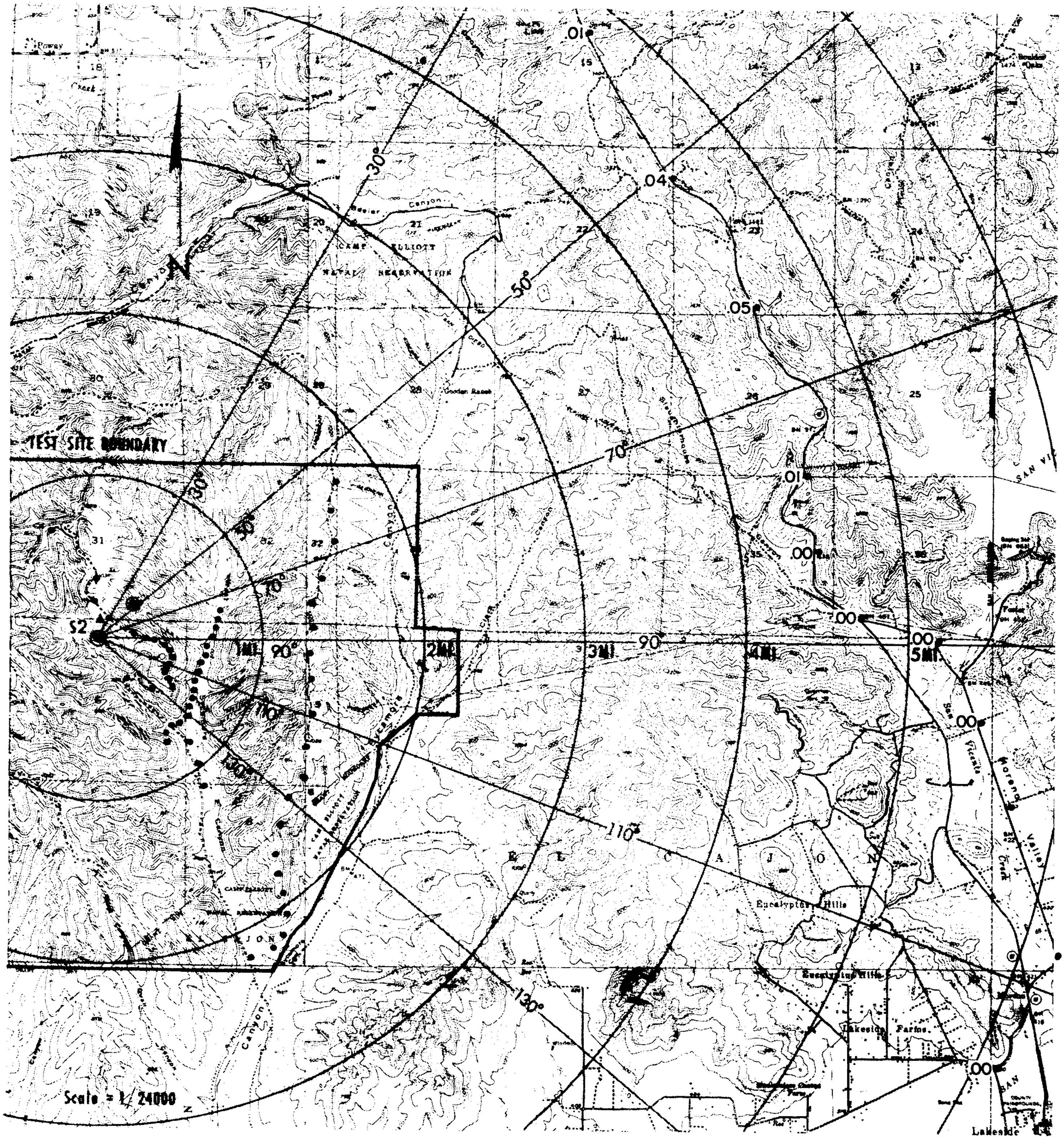
LF_2/LO_2 Ignition Time: 0942 PDT
FP Release (G): 0942:04
Dosages: ppm-min for 100 lbs F_2

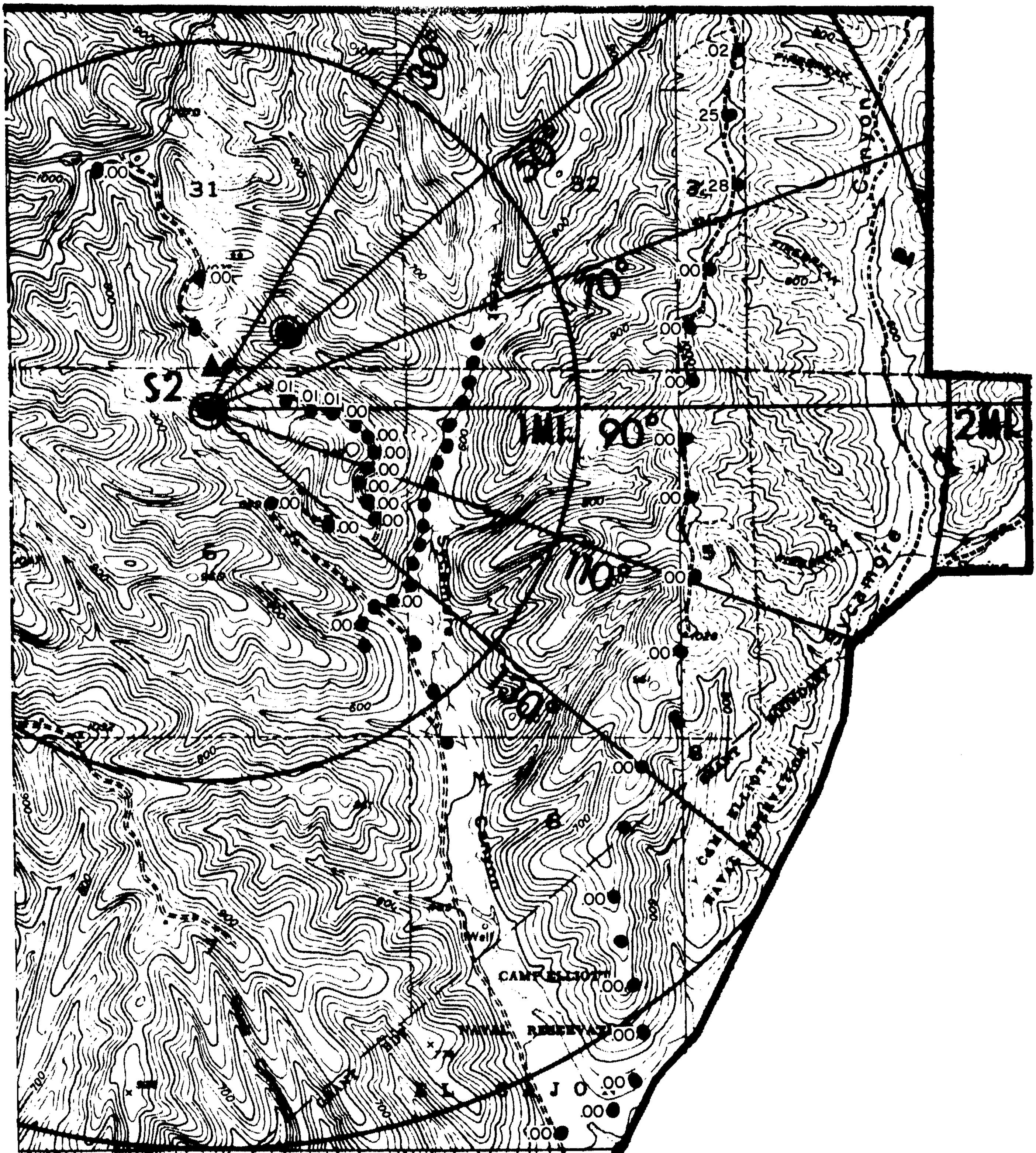


Trial: 31
Date: 12 October 1965
FP Release (Y): 1437:00
Dosages: ppm-min for 100 lbs F_2



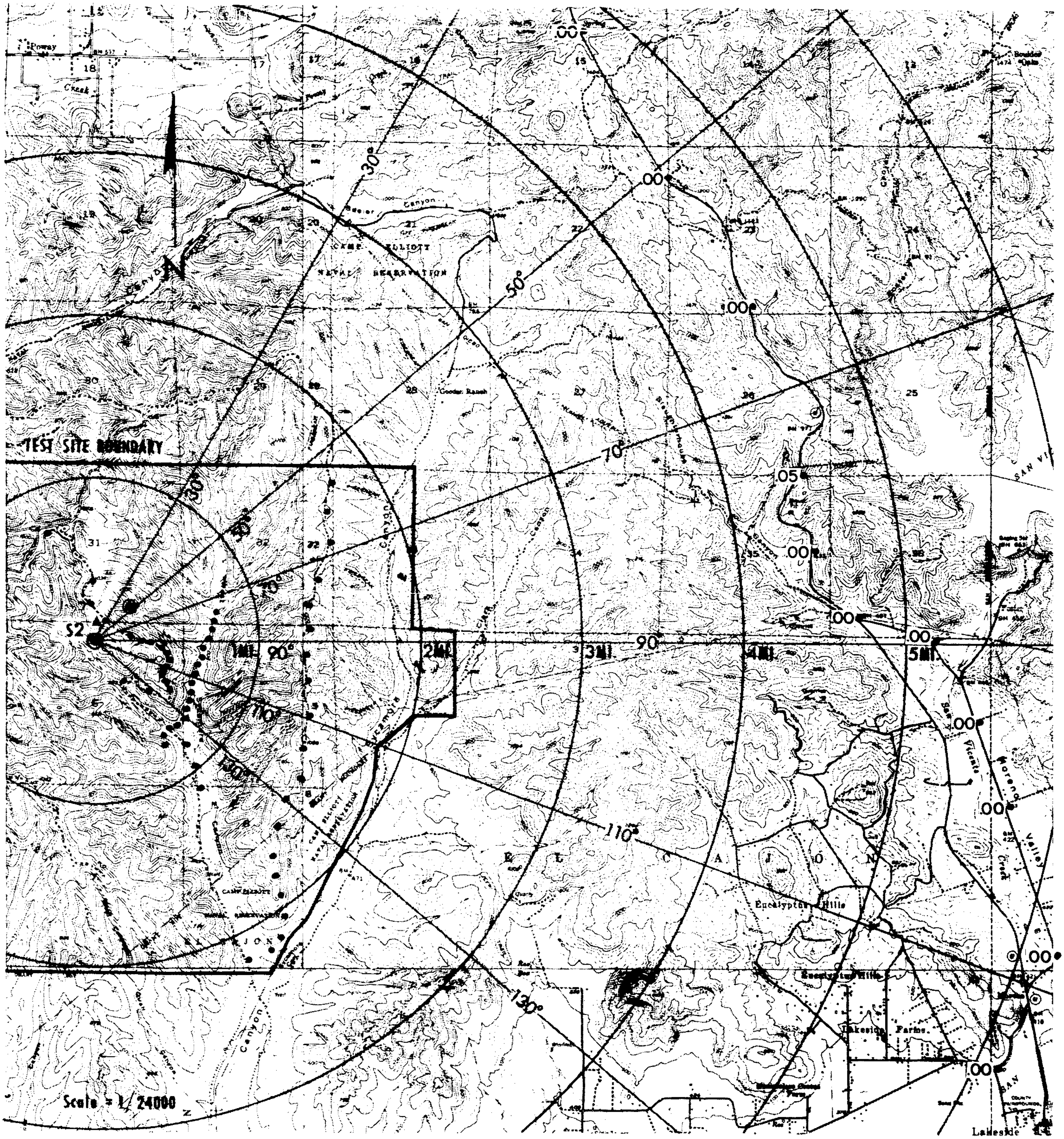
SYCAMORE TEST SITE, DOWNWIND SECTOR

Trial: 31
Date: 12 October 1965
FP Release (Y): 1437:00
Dosages: ppm-min for 100 lbs F_2



Trial: 31
Date: 12 October 1965
FP Release (G): 1419:00-1419:15
Dosages: ppm-min for 100 lbs F_2

FP DOSAGES



SYCAMORE TEST SITE, DOWNWIND SECTOR

Trial: 31
Date: 12 October 1965
FP Release (G): 1419:00-1419:15
Dosages: ppm-min for 100 lbs F_2

METEOROLOGICAL DATA

Project: Sycamore Canyon

wd: deg
ws: mph
temp: °F
σ: deg
Y: yellow

Trial: 1
Date: 27 April 1965
FP Release (Y): 1815-1816.5 PDT

Site: S-2 Gantry (MRI)

Time	wd	ws	Temp 138 ft	ΔT 138-63 ft	Horiz σ_{30}	Vert σ_{30}
1810-1815	NNW	5.1	69.3	-1.4	10.0	6.5
1815-1820	WNW	3.4	69.6	-1.4	15.1	8.0
1820-1825	WNW	4.3	68.9	-1.3	11.0	6.5
1825-1830	NW	4.3	68.5	-1.4	7.1	5.2
1830-1835	WSW	4.3	68.2	-1.4	8.0	5.0
1835-1840	WNW	2.7	67.6	-0.7	6.9	5.0
1840-1845	NNW	4.3	67.6	-1.1	10.0	6.0

Site:	Ridge Tower (MRI)		S-2 Tower (GD)		Met Site (GD)	
Time	wd	ws	wd	ws	wd	ws
1810-1815	WSW	5.1	W	4.5	W	8.1
1815-1820	WSW	5.6	W	4.5	W	8.1
1820-1825	WSW	6.3	W	4.5	WNW	8.1
1825-1830	WSW	6.5	W	4.5	WNW	12.3
1830-1835	WSW	6.5	WNW	4.5	WNW	12.3
1835-1840	WSW	6.0	W	4.5	WNW	9.8
1840-1845	WSW	6.0	W	4.5	W	9.8

METEOROLOGICAL DATA

Project: Sycamore Canyon

Trial: 2
Date: 28 April 1965
FP Release (Y): 1123-1124.5 PDT

wd: deg
ws: mph
temp: °F
σ deg
Y: yellow
M: missing

Site: S-2 Gantry (MRI)

Time	wd	ws	Temp 138 ft	ΔT 138-63 ft	Horiz σ_{30}	Vert σ_{30}
1115-1120	NNW	5.1	85.6	-4.7	16.0	6.6
1120-1125	NNW	6.3	85.6	-2.3	14.8	8.0
1125-1130	NNW	5.1	85.6	-2.3	15.1	7.5
1130-1135	NNW	5.1	85.1	-2.2	14.9	7.3
1135-1140	NNW	6.7	84.3	-2.2	13.5	9.6
1140-1145	N	4.3	86.5	-1.6	14.0	7.0
1145-1150	N	1.8	87.1	-1.8	20.7	9.3

Site:	Ridge Tower (MRI)		S-2 Tower (GD)		Met Site (GD)	
Time	wd	ws	wd	ws	wd	ws
1115-1120	NNW	6.0	NNE	3	WNW	4.9
1120-1125	NNW	5.1	NNW	3	WNW	4.9
1125-1130	NNW	5.1	NW	4	WNW	4.9
1130-1135	NNW	5.1	NNW	4	NW	6.0
1135-1140	NNW	5.6	NNW	4	NW	6.0
1140-1145	NNW	6.0	NW	3	WNW	6.0
1145-1150	NW	6.3	NW	2	NW	M

METEOROLOGICAL DATA

Project: Sycamore Canyon

Trial: 3
Date: 28 April 1965
FP Release (Y): 1307-1308.5 PDT

wd: deg
ws: mph
temp: °F
σ: deg
Y: yellow

Site: S-2 Gantry (MRI)

Time	wd	ws	Temp 138 ft	ΔT 138-63 ft	Horiz σ_{30}	Vert σ_{30}
1255-1300	NNW	5.1	M	M	18.5	6.3
1300-1305	WNW	3.4	>89.6	-1.3	15.0	4.8
1305-1310	N	5.1	>89.6	-1.1	13.0	8.5
1310-1315	WNW	3.4	>89.6	0.0	14.0	8.5
1315-1320	WNW	5.1	89.2	-0.9	15.5	9.6
1320-1325	WNW	10.1	88.5	-0.9	15.1	7.9
1325-1330	WNW	8.5	88.2	-0.7	11.1	5.2

Site:	Ridge Tower (MRI)		S-2 Tower (GD)		Met Site (GD)	
Time	wd	ws	wd	ws	wd	ws
1255-1300	SSE	3.4	SE	2.2	WNW	6.0
1300-1305	SW	5.4	SSW	4.5	W	4.0
1305-1310	SW	3.6	WNW	4.5	WNW	6.0
1310-1315	SE	2.2	W	4.5	NNW	8.1
1315-1320	WSW	3.6	NNW	4.5	WNW	9.2
1320-1325	WSW	9.6	WNW	6.7	WNW	8.1
1325-1330	WSW	9.6	WNW	8.9	WNW	8.1

METEOROLOGICAL DATA

Project: Sycamore Canyon

Trial: 4
Date: 28 April 1965
FP Release (Y): 1405-1406.5 PDT

wd: deg
ws: mph
temp: °F
σ: deg
Y: yellow

Site: S-2 Gantry (MRI)

Time	wd	ws	Temp 138 ft	ΔT 138-63 ft	Horiz σ_{30}	Vert σ_{30}
1355-1400	WNW	8.5	87.8	-0.7	10.8	4.0
1400-1405	W	11.0	88.9	-0.7	10.5	3.5
1405-1410	W	9.4	88.9	-0.7	12.0	4.3
1410-1415	WNW	8.5	88.9	-1.1	11.0	4.8
1415-1420	WNW	11.9	89.6	-0.9	12.5	6.5
1420-1425	W	9.4	88.7	-1.1	11.0	5.3
1425-1430	WSW	7.6	86.9	-0.5	11.4	3.8

Site:	Ridge Tower (MRI)		S-2 Tower (GD)		Met Site (GD)	
Time	wd	ws	wd	ws	wd	ws
1355-1400	W	11.4	WNW	5.0	WNW	8.1
1400-1405	WSW	11.6	WNW	6.0	WNW	10.1
1405-1410	WSW	13.2	WNW	6.0	WNW	10.1
1410-1415	WSW	12.5	WNW	6.0	W	10.1
1415-1420	WSW	12.1	W	5.0	WNW	10.1
1420-1425	W	12.1	WNW	6.0	W	10.1
1425-1430	WSW	14.1	W	8.0	WNW	11.2

METEOROLOGICAL DATA

Project: Sycamore Canyon

Trial: 5
Date: 28 April 1965
FP Release (Y): 1603-1604.5 PDT

wd: deg
ws: mph
temp: °F
σ: deg
Y: yellow

Site: S-2 Gantry (MRI)

Time	wd	ws	Temp 138 ft	ΔT 138-63 ft	Horiz σ_{30}	Vert σ_{30}
1555-1600	W	5.1	81.7	-1.8	22.5	11.5
1600-1605	W	6.7	78.8	-1.3	15.3	9.4
1605-1610	WSW	4.7	76.3	-2.9	17.5	9.0
1610-1615	SW	6.7	76.6	-2.2	13.2	8.8
1615-1620	SW	9.4	75.6	-1.8	12.0	7.7
1620-1625	SW	6.7	75.6	-1.4	11.5	6.3
1625-1630	W	5.1	74.5	-0.9	12.0	5.5

Site:	Ridge Tower (MRI)		S-2 Tower (GD)		Met Site (GD)	
Time	wd	ws	wd	ws	wd	ws
1555-1600	WSW	8.5	W	4.0	SW	4.9
1600-1605	WSW	8.3	WNW	4.0	SW	6.0
1605-1610	WSW	8.5	W	3.0	SW	4.9
1610-1615	WSW	6.3	WSW	2.0	SSW	6.0
1615-1620	SSW	9.4	WSW	2.0	SSW	6.0
1620-1625	SSW	8.9	SSW	3.0	SW	6.0
1625-1630	SSW	8.5	WNW	3.0	SW	4.9

METEOROLOGICAL DATA

Project: Sycamore Canyon

Trial: 6
Date: 29 April 1965
FP Release (Y): 1057-1058.5 PDT

wd: deg
ws: mph
temp: °F
σ: deg
Y: yellow

Site: S-2 Gantry (MRI)

Time	wd	ws	Temp 138 ft	ΔT 138-63 ft	Horiz σ_{300}	Vert σ_{30}
1045-1050	WNW	3.4	78.4	-2.3	20.9	8.3
1050-1055	W	5.8	77.7	-2.3	18.6	8.0
1055-1100	WNW	5.8	77.7	-2.3	17.1	6.5
1100-1105	WNW	5.8	77.7	-1.6	14.7	7.0
1105-1110	WNW	5.6	77.7	-1.6	18.6	6.1
1110-1115	WNW	4.3	78.4	-1.6	24.8	7.4
1115-1120	W	5.8	79.2	-2.7	24.8	8.7
1120-1125	WNW	6.3	79.7	-1.1	24.8	11.4
1125-1130	WNW	6.3	80.1	-1.1	20.1	6.7

Site:	Ridge Tower (MRI)		S-2 Tower (GD)		Met Site (GD)	
Time	wd	ws	wd	ws	wd	ws
1045-1050	WSW	6.0	W	3.0	NW	4.0
1050-1055	WSW	5.6	W	2.0	WNW	6.0
1055-1100	WSW	7.2	W	4.0	WNW	6.0
1100-1105	WSW	6.9	W	3.0	WNW	4.9
1105-1110	WSW	6.9	W	3.0	NW	4.0
1110-1115	WSW	5.6	W	4.0	NW	6.0
1115-1120	WSW	5.8	WNW	3.0	NW	4.9
1120-1125	WSW	4.3	W	1.0	NW	4.9
1125-1130	NW	6.0	WNW	3.0	NW	4.9

METEOROLOGICAL DATA

Project: Sycamore Canyon

wd: deg
ws: mph
temp: °F
σ: deg
Y: yellow

Trial: 7
Date: 29 April 1965
FP Release (Y): 1305-1306.5 PDT

Site: S-2 Gantry (MRI)

Time	wd	ws	Temp 138 ft	ΔT 138-63 ft	Horiz σ_{300}	Vert σ_{30}
1255-1300	WNW	8.5	82.2	-1.1	11.6	6.8
1300-1305	WNW	6.7	82.2	-1.1	12.4	6.1
1305-1310	W	6.7	82.9	-1.4	17.8	5.8
1310-1315	W	5.8	82.8	-1.4	22.5	7.0
1315-1320	W	6.7	81.7	-0.9	20.9	6.9
1320-1325	WNW	8.5	80.4	-0.7	17.0	6.5
1325-1330	W	6.7	80.4	-1.3	16.3	7.3

Site:	Ridge Tower (MRI)		S-2 Tower (GD)		Met Site (GD)	
Time	wd	ws	wd	ws	wd	ws
1255-1300	WSW	8.5	WNW	4.0	WNW	6.0
1300-1305	WSW	7.8	WNW	4.0	WNW	6.0
1305-1310	WSW	7.8	WNW	4.0	WNW	4.9
1310-1315	WSW	8.7	WNW	5.0	W	6.0
1315-1320	WSW	11.4	W	5.0	W	7.2
1320-1325	WSW	12.1	WNW	5.0	W	6.0
1325-1330	WSW	9.8	WNW	5.0	WNW	7.2

METEOROLOGICAL DATA

Project: Sycamore Canyon

Trial: 8
Date: 8 June 1965
Start LO_2 Flow: 1426 PDT
FP Release (Y): 1450-1451.5

wd: deg
ws: mph
temp: °F
σ: deg
Y: yellow

Site: S-2 Gantry (MRI)

Time	wd	ws	Temp 138 ft	ΔT 138-63 ft
1420-1425	SW	7.6	60.4	-1.8
1425-1430	SW	7.6	60.4	-1.8
1430-1435	W	6.7	60.4	-1.8
1435-1440	SW	8.5	62.1	-1.8
1440-1445	WSW	7.6	62.1	-1.8
1445-1450	SW	7.6	60.3	-1.8
1450-1455	SW	8.5	59.9	-1.8
1455-1500	WSW	8.5	59.4	-1.8
1500-1505	SW	9.4	59.4	-1.8
1505-1510	SW	8.5	59.2	-1.8
1510-1515	SW	8.5	59.4	-1.3
1515-1520	SW	9.4	58.8	-1.3
1520-1530			59.0	-1.4
1530-1540			58.8	-1.1
1540-1550			57.7	-1.3

Site: Ridge Tower (MRI) S-2 Tower (GD)

Time	Ridge Tower (MRI) wd	Ridge Tower (MRI) ws	S-2 Tower (GD) wd	S-2 Tower (GD) ws
1420-1425	SW	9.4	W	4.9
1425-1430	SW	12.8	W	4.0
1430-1435	WSW	11.0	W	4.0
1435-1440	SW	11.9	W	4.0
1440-1445	SW	12.8	W	4.0
1445-1450	SW	11.9	WNW	4.0
1450-1455	SW	14.3	SSW	2.0
1455-1500	SW	17.0	W	3.1
1500-1505	SW	17.0	W	3.1
1505-1510	SW	15.2	W	4.0
1510-1515	SW	11.9	WSW	6.0
1515-1520	SW	17.0	SW	6.0

METEOROLOGICAL DATA

Project: Sycamore Canyon

wd: deg
ws: mph
temp: °F
σ: deg
Y: yellow
M: missing

Trial: 9
Date: 9 June 1965
Start LO_2 Flow: 1226 PDT
FP Release (Y): 1310-1311.5

Site: S-2 Gantry (MRI)

Time	wd	ws	Temp 138 ft	ΔT 138-63 ft	Horiz σ_{300}	Vert σ_{30}
1220-1225	SW	8.5	61.2	-1.6	21.5	No data
1225-1230	WSW	11.0	61.2	-1.6	17.0	
1230-1235	WSW	9.4	62.8	-1.8	19.4	
1235-1240	W	7.6	62.8	-1.8	19.8	
1240-1245	WNW	8.5	63.0	-1.8	22.4	
1245-1250	WSW	7.6	62.8	-2.7	24.0	
1250-1255	W	8.5	62.8	-2.7	24.4	
1255-1300	W	9.4	63.0	-2.7	27.9	
1300-1305	W	8.5	63.0	-2.7	25.6	
1305-1310	W	8.5	62.4	-2.0	25.2	
1310-1315	WSW	8.5	62.4	-2.0	24.4	
1315-1320	WSW	8.5	61.2	-1.3	23.3	
1320-1325	W	6.7	61.2	-1.3	26.8	
1325-1330	W	5.8	61.9	-1.6	M	
1330-1335	W	5.8	61.9	-1.6	29.1	
1335-1340	W	5.8	61.9	-1.6		
1340-1350	W	5.9	61.7	-1.3		
1350-1400	W	5.9	62.6	-1.3		
1400-1410			63.9	-1.3		

Site: Ridge Tower (MRI) S-2 Tower (GD)

Time	Ridge Tower (MRI) wd	Ridge Tower (MRI) ws	S-2 Tower (GD) wd	S-2 Tower (GD) ws
1220-1225	SW	11.0	WSW	3.0
1225-1230	SW	12.8	SSW	4.0
1230-1235	SW	10.1	SW	6.0
1235-1240	WSW	11.0	SSW	4.0
1240-1245	WSW	11.0	W	5.0
1245-1250	W	11.9	WNW	6.0
1250-1255	WSW	14.3	W	4.0
1255-1300	WSW	15.2	WNW	6.0
1300-1305	WSW	13.4	W	4.0
1305-1310	WSW	15.2	WSW	4.0
1310-1315	SW	11.9	W	6.0
1315-1320	WSW	12.8	SSW	3.0
1320-1325	WSW	12.8	WSW	5.0
1325-1330	WSW	11.0	WNW	4.0
1330-1335	WSW	10.1	WNW	5.0
1335-1340	WSW	9.4	WNW	5.0

METEOROLOGICAL DATA

Project: Sycamore Canyon

Trial: 10
Date: 11 June 1965
Start LO_2 Flow: 0930 PDT
FP Release (Y): 0950-0951.5

wd: deg
ws: mph
temp: °F
σ: deg
Y: yellow
M: missing

Site: S-2 Gantry (MRI)

Time	wd	ws	Temp 138 ft	ΔT 138-63 ft	Horiz σ_{300}	Vert σ_{30}
0900-0905	NNW	5.1	59.4	0.2	19.8	No
0905-0910	NNW	4.3	59.4	0.2	18.6	data
0910-0915	NNW	3.4	61.5	0.2	19.4	
0915 0920	WNW	2.5	61.5	0.2	19.4	
0920-0925	NNW	2.5	63.1	1.3	24.0	
0925-0930	NNE	1.8	63.1	1.3	24.4	
0930-0935	N	2.5	63.7	0.2	M	
0935-0940	NNW	4.3	63.7	0.2	M	
0940-0945	NW	3.4	65.3	0.0	18.6	
0945-0950	NNW	2.5	65.3	0.0	22.5	
0950-0955	NW	3.4	65.3	-0.5	26.8	
0955-1000	NNW	3.4	65.3	-0.5	32.0	
1000-1005	NNW	3.4	65.7	-2.5	M	
1005-1010	NNW	3.4	65.7	-2.5	M	
1010-1015	N	3.4	68.7	-2.3	24.4	
1015-1020	WNW	3.4	68.7	-2.3		
1020-1030			68.7	-2.3		
1030-1040			68.7	2.3		
1040-1050			69.1	-2.5		

Site: Time	Ridge Tower (MRI) wd	ws	S-2 Tower (GD) wd	ws
0900-0905	WNW	5.1	N	1.0
0905-0910	WNW	3.4	WNW	2.0
0910-0915	W	3.4	NW	2.0
0915-0920	NNW	5.1	N	2.0
0920-0925	NNW	3.4	N	2.0
0925-0930	NNW	3.4	WNW	2.0
0930-0935	NNE	3.4	WNW	1.0
0935-0940	N	2.5	N	<1.0
0940-0945	WNW	4.3	NE	1.0
0945-0950	N	5.1	NNW	1.0
0950-0955	SW	2.5	NW	1.0
0955-1000	WSW	4.3	WNW	1.0
1000-1005	WNW	4.3	N	<1.0
1005-1010	NNW	3.4	N	<1.0
1010-1015	NNW	4.3	WNN	1.0
1015-1020	WNW	5.1	W	1.0

METEOROLOGICAL DATA

Project: Sycamore Canyon

wd: deg
ws: mph
temp: °F
σ: deg
Y: yellow

Trial: 11
Date: 14 June 1965
Start LO_2 Flow: 1415 PDT
FP Release (Y): 1459-1469

Site: S-2 Gantry (MRI)

Time	wd	ws	Temp 138 ft	ΔT 138-63 ft	Horiz σ_{300}	Vert σ_{300}
1410-1415	W	8.5	63.7	-1.8	22.7	No
1415-1420	WSW	8.5	63.7	-1.8	23.3	data
1420-1425	W	8.5	65.3	-2.5	25.2	
1425-1430	WSW	7.6	65.3	-2.5	26.4	
1430-1435	WSW	5.8	64.8	-2.5	33.3	
1435-1440	WSW	6.7	64.0	-2.0	35.6	
1440-1445	WSW	8.5	64.0	-2.0	34.9	
1445-1450	W	5.8	64.8	-0.4	29.4	
1450-1455	W	7.6	64.8	-0.4	28.7	
1455-1500	W	8.5	63.9	-1.3	31.4	
1500-1505	WSW	8.5	63.9	-1.3	29.0	
1505-1510	WSW	10.1	64.9	-0.5	18.6	
1510-1515	WSW	7.6	64.9	-0.5	24.8	
1515-1520	WSW	7.6	64.9	-1.3	25.6	
1520-1525	W	8.5	64.9	-1.3	32.5	
1525-1530	W	7.6	64.9	-1.6	24.4	
1530-1535	WSW	5.8	64.9	-1.6		
1535-1540	W	7.6	64.4	-1.6		
1540-1550			64.9	-1.8		
1550-1600			64.8	-2.0		

Site: Ridge Tower (MRI) / S-2 Tower (GD)

Time	Ridge Tower (MRI) wd	Ridge Tower (MRI) ws	S-2 Tower (GD) wd	S-2 Tower (GD) ws
1410-1415	SW	15.2	WSW	5.0
1415-1420	SW	12.8	W	5.0
1420-1425	SW	15.2	WSW	5.0
1425-1430	SW	11.9	W	5.0
1430-1435	WSW	11.9	SSW	6.0
1435-1440	SSW	13.4	W	4.0
1440-1445	SW	16.1	W	3.0
1445-1450	SW	16.1	W	6.0
1450-1455	SW	13.4	WSW	5.0
1455-1500	SW	15.2	W	4.0
1500-1505	SW	15.2	W	6.0
1505-1510	SW	16.1	W	6.0
1510-1515	SW	15.2	WSW	6.0
1515-1520	SW	16.1	SW	7.0
1520-1525	SW	14.3	SSW	4.0
1525-1530	SW	12.8	SW	4.0
1530-1535	WSW	11.0	WSW	4.0
1535-1540	SW	11.9	W	6.0

METEOROLOGICAL DATA

Project: Sycamore Canyon

wd: deg
ws: mph
temp: °F
σ: deg
Y: yellow

Trial: 12
Date: 17 June 1965
Start LO_2 Flow: 0939 PDT
FP Release (Y): 1009-1019

Site: S-2 Gantry (MRI)

Time	wd	ws	Temp 138 ft	ΔT 138-63 ft	Horiz σ_{300}	Vert
0935-0940	SW	1.8	57.7	-0.2	20.9	No
0940-0945	WNW	4.3	57.7	-0.2	19.8	data
0945-0950	WNW	4.3	60.5	-0.4	20.5	
0950-0955	WNW	4.3	60.5	-0.4	16.7	
0955-1000	WNW	2.5	60.5	-0.4	13.6	
1000-1005	WNW	4.3	60.5	-0.7	12.0	
1005-1010	W	4.3	60.5	-0.7	14.0	
1010-1015	W	2.5	57.7	-1.1	19.8	
1015-1020	WNW	3.4	57.7	-1.1	24.4	
1020-1025	WNW	5.1	57.7	-0.9	23.2	
1025-1030	NNW	5.8	60.5	-1.1	17.1	
1030-1035	NNW	5.1	60.5	-1.1	10.8	
1035-1040	NW	4.3	58.1	-1.3	13.9	
1040-1050			57.6	-1.1		
1050-1100			59.2	-1.8		
1100-1110			61.2	-1.8		

Site:	Ridge Tower (MRI)		S-2 Tower (GD)	
Time	wd	ws	wd	ws
0935-0940	WSW	5.1	W	2.0
0940-0945	W	5.6	WNW	1.0
0945-0950	W	4.3	WNW	1.0
0950-0955	WSW	4.3	WNW	2.0
0955-1000	SW	5.1	WNW	4.0
1000-1005	WSW	5.6	WNW	2.0
1005-1010	WSW	5.6	W	2.0
1010-1015	WSW	3.4	W	3.0
1015-1020	NNW	3.4	WNW	3.0
1020-1025	NNW	5.1	W	2.0
1025-1030	NW	5.6	W	2.0
1030-1035	NW	5.6	NW	2.0
1035-1040	NW	3.4	N	2.0
1040-1050				

METEOROLOGICAL DATA

Project: Sycamore Canyon

wd: deg
ws: mph
temp: °F
σ: deg
Y: Yellow

Trial: 13
Date: 24 June 1965
Start LF_2/LO_2 Flow: 1158 PDT
FP Release (Y): 1220-1228

Site: S-2 Gantry (MRI)

Time	wd	ws	Temp 138 ft	ΔT 138-63 ft	Horiz σ30	Vert σ30
1140-1145	WNW	8.5	63.1	-1.4	13.0	6.5
1145-1150	NW	7.6	63.1	-1.4	8.0	6.2
1150-1155	NW	6.7	63.7	-1.4	7.0	5.5
1155-1200	NW	7.6	63.7	-1.4	6.0	5.5
1200-1205	WNW	7.6	63.4	-0.7	6.0	5.8
1205-1210	NW	6.7	63.4	-0.7	6.0	5.5
1210-1215	NW	6.7	63.0	-1.1	5.0	5.3
1215-1220	NW	7.6	63.0	-1.1	4.0	6.5
1220-1225	WNW	6.7	63.6	-1.1	4.0	5.5
1225-1230	WNW	6.7	63.6	-1.1	5.0	5.5
1230-1235	WNW	6.7	63.6	-1.1	6.0	4.8
1235-1240	WNW	9.4	63.8	-1.3	5.0	4.0
1240-1245	WNW	8.5	63.8	-1.3	2.0	5.0
1245-1250	WNW	6.7	63.1	-1.3	5.0	6.8
1250-1255	WNW	8.5	63.1	-1.3	4.0	4.0
1255-1300	WNW	7.6	63.1	-1.3	5.0	6.3
1300-1310			63.1	-1.3		
1310-1320			63.7	-1.3		

Site: Ridge Tower (MRI)

Time	wd	ws
1140-1145	WSW	5.8
1145-1150	WSW	8.5
1150-1155	W	5.8
1155-1200	W	6.8
1200-1205	WNW	8.5
1205-1210	W	11.0
1210-1215	W	10.1
1215-1220	W	8.5
1220-1225	WSW	8.5
1225-1230	WSW	10.1
1230-1235	WSW	11.9
1235-1240	W	11.9
1240-1245	W	11.9
1245-1250	W	11.0
1250-1255	W	8.5
1255-1300	W	8.5

METEOROLOGICAL DATA

Project: Sycamore Canyon

wd: deg
ws: mph
temp: °F
σ: deg
Y: Yellow

Trial: 14
Date: 24 June 1965
Start LF_2/LO_2 Flow: 1625 PDT
FP Release (Y): 1643-1650

Site: S-2 Gantry (MRI)

Time	wd	ws	Temp 138 ft	ΔT 138-63 ft	Horiz σ30	Vert σ30
1620-1625	NW	9.4	62.8	-1.6	5.0	6.0
1625-1630	NW	8.5	62.8	-1.6	5.0	6.5
1630-1635	NW	9.4	63.2	-1.4	3.0	5.3
1635-1640	WNW	8.5	63.2	-1.4	4.0	6.3
1640-1645	NW	8.5	62.6	-0.9	4.0	6.3
1645-1650	NW	8.5	62.6	-0.9	5.0	6.0
1650-1655	WNW	10.1	62.8	-1.3	4.0	5.0
1655-1700	WNW	8.5	62.8	-1.3	5.0	6.5
1700-1710			63.0	-1.3		
1710-1720			63.0	-1.3		
1720-1730			61.2	-1.4		
1730-1740			61.2	-0.5		

Site: Ridge Tower (MRI)

Time	wd	ws
1620-1625	W	8.5
1625-1630	W	8.5
1630-1635	W	11.9
1635-1640	WNW	9.4
1640-1645	W	10.1
1645-1650	W	10.1
1650-1655	W	11.9
1655-1700	W	10.1

METEOROLOGICAL DATA

Project: Sycamore Canyon

wd: deg
ws: mph
temp: °F
σ: deg
Y: yellow

Trial: 15
Date: 25 June 1965
FP Release (Y): 1335-1345

Site: S-2 Gantry (MRI)

Time	wd	ws	Temp 138 ft	ΔT 138-63 ft	Horiz σ30	Vert σ30
1330-1335	SSW	6.7	55.8	0.9	15.0	7.8
1335-1340	SSW	7.6	55.8	0.9	13.0	6.8
1340-1345	S	4.3	55.8	0.9	16.0	7.4
1345-1350	SSW	5.1	56.1	0.9	24.0	9.8
1350-1355	SSW	8.5	56.1	0.9	12.0	7.0
1355-1400	SSW	8.5	56.1	0.9	7.0	5.9
1400-1410			56.1	0.9		
1410-1420			56.3	1.3		
1420-1430			56.3	1.3		

Site: Ridge Tower (MRI)

Time	wd	ws
1330-1335	S	9.4
1335-1340	S	11.0
1340-1345	S	11.0
1345-1350	S	11.9
1350-1355	S	11.9
1355-1400	S	11.9

METEOROLOGICAL DATA

Project: Sycamore Canyon

wd: deg
ws: mph
temp: °F
σ: deg

Trial: 18
Date: 6 July 1965
LF_2/LO_2 Ignition Time: 1448 PDT

Site: S-2 Gantry (MRI)

Time	wd	ws	Temp 138 ft	ΔT 138-63 ft	Horiz σ_{30}	Vert σ_{30}
1440-1445	W	4.2	79.5	-0.4	22.2	4.7
1445-1450	W	5.1	79.2	-0.4	24.8	2.7
1450-1455	W	5.1	79.0	-0.9	25.6	4.0
1455-1500	SW	5.9	79.2	-0.9	29.4	3.7
1500-1505	WNW	5.9	79.3	+0.2	28.0	2.3
1505-1510	WSW	5.1	79.3	+0.2	26.8	2.7
1510-1515	WSW	5.1	79.2	+0.5	21.3	3.0
1515-1520	W	6.8	78.8	+0.2	20.1	3.0
1520-1530	WSW	6.8	78.8	-0.9	25.6	4.7
1530-1540	SW	7.6	78.6	-1.1	22.9	4.2
1540-1550	W	4.6	78.3	-0.9	26.0	3.2

Site: Ridge Tower (MRI)

Time	wd	ws
1440-1445	W	8.4
1445-1450	W	8.4
1450-1455	W	8.4
1455-1500	W	7.6
1500-1505	W	9.3
1505-1510	W	9.3
1510-1515	WSW	7.6
1515-1520	WSW	8.4
1520-1530	WSW	8.4
1530-1540	WSW	8.4
1540-1550	W	8.0

METEOROLOGICAL DATA

Project: Sycamore Canyon

Trial: 19
Date: 8 July 1965
LF_2/LO_2 Ignition Time: 1340 PDT
FP Release (Y): 1339:53-1340:08

wd: deg
ws: mph
temp: °F
σ: deg
Y: yellow

Site: S-2 Gantry (MRI)

Time	wd	ws	Temp 138 ft	ΔT 138-63 ft
1335-1340	W	7.6	74.5	-0.9
1340-1345	WSW	7.6	74.5	-0.9
1345-1350	SW	8.5	74.5	0.0
1350-1355	WSW	7.6	74.5	0.0
1355-1400	W	5.1	76.1	0.0

Site: Ridge Tower (MRI)

Time	wd	ws
1335-1340	W	9.4
1340-1345	W	9.4
1345-1350	W	10.1
1350-1355	W	10.1
1355-1400	WNW	10.1

METEOROLOGICAL DATA

Project: Sycamore Canyon

wd: deg
ws: mph
temp: °F
σ: deg
Y: yellow

Trial: 20
Date: 12 July 1965
LF_2/LO_2 Ignition Time: 1529 PDT
FP Release (Y): 1528:50-1529:05

Site: S-2 Gantry (MRI)

Time	wd	ws	Temp 138 ft	ΔT 138-63 ft	Horiz σ_{30}	Vert σ_{30}
1520-1525	WSW	5.8	67.6	-0.5	14.4	7.8
1525-1530	WSW	6.7	68.5	-0.9	16.0	9.0
1530-1535	WSW	5.1	68.5	-0.9	11.2	10.3
1535-1540	WSW	5.8	70.7	-0.7	10.8	7.7
1540-1545	WSW	5.1	70.7	-0.7	8.9	8.0
1545-1550	W	5.8	70.7	-0.9	12.0	7.0
1550-1555	WSW	7.6	70.7	-0.9	13.3	6.5
1555-1600	WSW	5.9	68.5	-0.9	13.0	6.5

Site: Ridge Tower (MRI)

Time	wd	ws
1520-1525	WSW	8.5
1525-1530	WSW	9.4
1530-1535	WSW	10.1
1535-1540	WSW	11.9
1540-1545	WSW	8.5
1545-1550	WSW	8.5
1550-1555	W	9.4
1555-1600	WSW	10.1

METEOROLOGICAL DATA

Project: Sycamore Canyon

wd: deg
ws: mph
temp: °F
σ: deg
Y: yellow
G: green

Trial: 21
Date: 19 July 1965
LF_2/LO_2 Ignition Time: 1500 PDT
FP Release (Y): 1459:50-1500:05
(G): 1510:00-1510:15

Site: S-2 Gantry (MRI)

Time	wd	ws	Temp 138 ft	ΔT 138-63 ft	Horiz σ_{30}	Vert σ_{30}
1455-1500	WNW	7.6	78.4	-0.7	17.0	7.3
1500-1505	W	6.7	78.4	-0.9	18.0	7.0
1505-1510	W	7.6	78.1	-0.9	18.0	8.0
1510-1515	W	6.7	78.1	-0.9	17.0	7.7
1515-1520	WNW	6.7	77.9	-0.2	17.0	7.6
1520-1525	WNW	7.6	77.9	-0.2	17.0	7.5
1525-1530	WNW	6.7	77.9	-0.2	19.0	6.2
1530-1535	WNW	9.4	77.9	-0.2	19.0	6.3
1535-1540	WNW	6.7	77.0	0.0	17.0	7.0

Site: Ridge Tower (MRI)

Time	wd	ws
1455-1500	WSW	12.8
1500-1505	WSW	11.0
1505-1510	WSW	10.1
1510-1515	W	10.1
1515-1520	W	11.0
1520-1525	WSW	11.0
1525-1530	W	11.0
1530-1535	W	11.9
1535-1540	W	11.9

METEOROLOGICAL DATA

Project: Sycamore Canyon

wd: deg
ws: mph
temp: °F
σ: deg
Y: yellow
G: green

Trial: 22
Date: 21 July 1965
LF_2/LO_2 Ignition Time: 1303 PDT
FP Release (Y): 1302:50-1303:05
(G): 1316:00-1316:15

Site: S-2 Gantry (MRI)

Time	wd	ws	Temp 138 ft	ΔT 138-63 ft	Horiz σ_{300}	Vert σ_{30}
1255-1300	WNW	6.7	76.6	-0.7	12.8	6.5
1300-1305	WNW	8.5	76.6	-0.7	11.6	6.3
1305-1310	WNW	8.5	77.9	-0.5	10.9	7.0
1310-1315	WNW	7.6	77.9	-0.5	10.9	6.0
1315-1320	W	7.6	77.9	-0.7	14.7	7.0
1320-1325	WNW	7.6	77.9	-0.7	19.0	7.0
1325-1330	WNW	6.7	77.0	-0.5	21.7	7.2
1330-1335	WNW	7.6	77.0	-0.5	20.1	6.9
1335-1340	WNW	8.5	77.0	-0.7	17.8	8.5
1340-1345	WNW	7.6	77.0	-0.7	15.5	6.2

Site: Ridge Tower (MRI)

Time	wd	ws
1255-1300	WNW	11.0
1300-1305	W	11.9
1305-1310	W	12.8
1310-1315	W	11.0
1315-1320	WSW	12.8
1320-1325	W	12.8
1325-1330	W	12.8
1330-1335	W	11.9
1335-1340	W	14.3
1340-1345	WSW	12.8

METEOROLOGICAL DATA

Project: Sycamore Canyon

wd: deg
ws: mph
temp: °F
σ: deg
Y: yellow
G: green
M: missing

Trial: 23
Date: 27 July 1965
LF_2/LO_2 Ignition Time: 1019 PDT
FP Release (Y): 1018:50-1019:05
(G): 1030:00-1030:15

Site: S-2 Gantry (MRI)

Time	wd	ws	Temp 138 ft	ΔT 138-63 ft	Horiz σ_{300}	Vert σ_{30}
1010-1015	NNW	3.4	70.9	M	24.2	9.5
1015-1020	NNW	4.3	M	0.7	21.2	8.2
1020-1025	N	4.3	M	0.7	23.6	9.5
1025-1030	NNW	3.4	71.6	M	19.8	8.6
1030-1035	NNW	4.3	71.6	M	20.6	8.2
1035-1040	NNW	4.3	M	2.2	20.1	9.0
1040-1045	NNW	5.1	M	M	17.8	9.3
1045-1050	NNW	5.1	M	M	16.3	8.2
1050-1055	NNW	5.8	M	M	18.2	8.7
1055-1100	NNW	5.1	M	M	12.8	9.6

Site: Ridge Tower (MRI)

Time	wd	ws
1010-1015	NNW	5.1
1015-1020	NNW	5.1
1020-1025	NNW	5.8
1025-1030	NNW	5.8
1030-1035	NW	4.3
1035-1040	NNW	4.3
1045-1050	NNW	5.1
1055-1100	NNW	5.1

METEOROLOGICAL DATA

Project: Sycamore Canyon

Trial: 24
Date: 30 July 1965
LF_2/LO_2 Ignition Time: 1337 PDT
FP Release (Y): 1336:53-1337:08
(G): 1347:00-1347:15

wd: deg
ws: mph
temp: °F
σ: deg
Y: yellow
G: green
M: missing

Site: S-2 Gantry (MRI)

Time	wd	ws	Temp 138 ft	ΔT 138-63 ft	Horiz σ_{300}	Vert σ_{30}
1330-1335	W	6.7	85.3	4.1	23.1	8.0
1335-1340	WNW	5.8	85.3	4.1	19.0	9.5
1340-1345	WNW	6.7	84.7	4.1	21.8	9.5
1345-1350	WNW	7.6	84.4	4.7	16.6	6.0
1350-1355	WNW	8.5	84.0	4.9	15.9	6.0
1355-1400	W	7.6	83.8	5.0	11.5	5.0
1400-1405	WNW	7.6	83.8	5.0	10.8	4.5
1405-1410	WNW	7.6	83.8	5.0	10.8	6.5
1410-1415	W	7.6	84.4	5.2	20.1	7.0
1415-1420	WNW	7.6	84.9	5.0	14.3	6.0

Site: Ridge Tower (MRI)

Time	wd	ws
1330-1335	WSW	M
1335-1340	W	M
1340-1345	W	M
1345-1350	WNW	M
1350-1355	W	M
1355-1400	W	M
1400-1405	W	M
1405-1410	WNW	M
1410-1415	WNW	M
1415-1420	WSW	M

METEOROLOGICAL DATA

Project: Sycamore Canyon

wd: deg
ws: mph
temp: °F
σ: deg
Y: yellow
G: green

Trial: 25
Date: 4 August 1965
LF_2/LO_2 Ignition Time: 1304 PDT
FP Release (Y): 1304:02
(G): 1302:00-1302:15

Site: S-2 Gantry (MRI)

Time	wd	ws	Temp 138 ft	ΔT 138-63 ft	Horiz σ_{300}	Vert σ_{30}
1255-1300	WSW	6.7	81.1	-0.7	21.9	8.5
1300-1305	WSW	7.6	81.1	-0.7	15.9	7.5
1305-1310	WSW	8.5	80.8	-0.7	21.7	5.5
1310-1315	WSW	8.5	80.8	-0.9	16.7	7.5
1315-1320	WSW	7.6	80.4	-0.9	12.4	7.0
1320-1325	WSW	11.0	80.1	-0.9	13.6	5.5
1325-1330	WSW	11.9	80.1	-1.1	12.0	6.5
1330-1335	WSW	9.4	80.2	-0.9	12.8	8.0

Site: Ridge Tower (MRI)

Time	wd	ws
1255-1300	W	10.1
1300-1305	WSW	11.0
1305-1310	WSW	11.9
1310-1315	W	12.8
1315-1320	W	11.0
1320-1325	W	11.0
1325-1330	WSW	11.0
1330-1335	W	10.1

METEOROLOGICAL DATA

Project: Sycamore Canyon

wd: deg
ws: mph
temp: °F
σ: deg
Y: yellow
G: green
M: missing

Trial: 26
Date: 9 August 1965
LF_2/LO_2 Ignition Time: 1033 PDT
FP Release (Y): 1033:04
(G): 1031:00-1031:15

Site: S-2 Gantry (MRI)

Time	wd	ws	Temp 138 ft	ΔT 138-63 ft	Horiz σ_{300}	Vert σ_{30}
1025-1030	NW	6.7	87.3	0.2	17.0	6.0
1030-1035	NNW	7.6	87.4	0.0	14.7	4.0
1035-1040	NNW	7.6	87.6	0.0	12.4	4.0
1040-1045	NNW	7.6	88.0	0.2	12.4	5.5
1045-1050	N	8.5	88.2	0.2	12.4	4.5
1050-1055	NNW	6.7	M	M	14.7	6.0
1055-1100	NNW	7.6	M	M	12.0	4.5
1100-1105	NNW	5.8	M	M	15.1	5.0

Site: Ridge Tower (MRI)

Time	wd	ws
1025-1030	NNW	8.5
1030-1035	NNW	8.5
1035-1040	NNW	8.5
1040-1045	N	7.6
1045-1050	NNW	8.5
1050-1055	NNW	9.4
1055-1100	NNW	7.6
1100-1105	NW	5.8

METEOROLOGICAL DATA

Project: Sycamore Canyon

wd: deg
ws: mph
temp: °F
σ: deg
Y: yellow
G: green
M: missing

Trial: 27
Date: 31 August 1965
LF_2/LO_2 Ignition Time: 1006:30 PDT
FP Release (Y): 1006:34
(G): 1009:00-1009:15

Site: S-2 Gantry (MRI)

Time	wd	ws	Temp 138 ft	ΔT 138-63 ft
1000-1005	WNW	3.4	76.8	-1.3
1005-1010	NW	3.4	76.8	-1.3
1010-1015	NW	5.1	77.2	-1.3
1015-1020	WNW	5.1	77.2	-1.3
1020-1025	NW	5.1	77.4	-0.9
1025-1030	NW	6.7	77.4	-0.9
1030-1035	NNW	7.6	M	M
1035-1040	NNW	7.6	M	M

Site: Ridge Tower (MRI)

Time	wd	ws
1000-1005	SW	7.6
1005-1010	WSW	9.4
1010-1015	W	11.4
1015-1020	WNW	13.2
1020-1025	WSW	9.4
1025-1030	W	7.6
1030-1035	W	11.4
1035-1040	WNW	11.4

METEOROLOGICAL DATA

Project: Sycamore Canyon

wd: deg
ws: mph
temp: °F
Y: yellow
G: green

Trial: 28
Date: 3 September 1965
LF_2/LO_2 Ignition Time: 0942 PDT
FP Release (Y): 0940:00-0940:15
(G): 0942:04

Site: S-2 Gantry (MRI)

Time	wd	ws	Temp 138 ft	ΔT 138-63 ft
0935-0940	NW	1.7	65.3	0.4
0940-0945	N	1.7	66.6	-0.4
0945-0950	WNW	1.7	66.6	-0.2
0950-0955	WNW	2.5	68.7	-0.2
0955-1000	WNW	3.4	68.7	-0.2
1000-1005			68.9	0.2
1005-1010			69.1	0.2
1010-1015			69.1	0.2

Site: Ridge Tower (MRI)

Time	wd	ws
0935-0940	SW	1.3
0940-0945	W	1.3
0945-0950	WNW	1.3
0950-0955	WNW	2.5
0955-1000	WNW	3.8

METEOROLOGICAL DATA

Project: Sycamore Canyon

Trial: 29
Date: 3 September 1965
FP Release (Y): 1407:00-1407:15

wd: deg
ws: mph
temp: °F
Y: yellow

Site: S-2 Gantry (MRI)

Time	wd	ws
1400-1405	SSW	8.4
1405-1410	SSW	6.8
1410-1415	SW	7.6
1415-1420	SSW	8.4
1420-1425	SSW	6.8
1425-1430	SSW	6.8
1430-1435	SSW	6.8
1435-1440	SSW	8.4

METEOROLOGICAL DATA

Project: Sycamore Canyon

wd: deg
ws: mph
temp: °F
Y: yellow
G: green

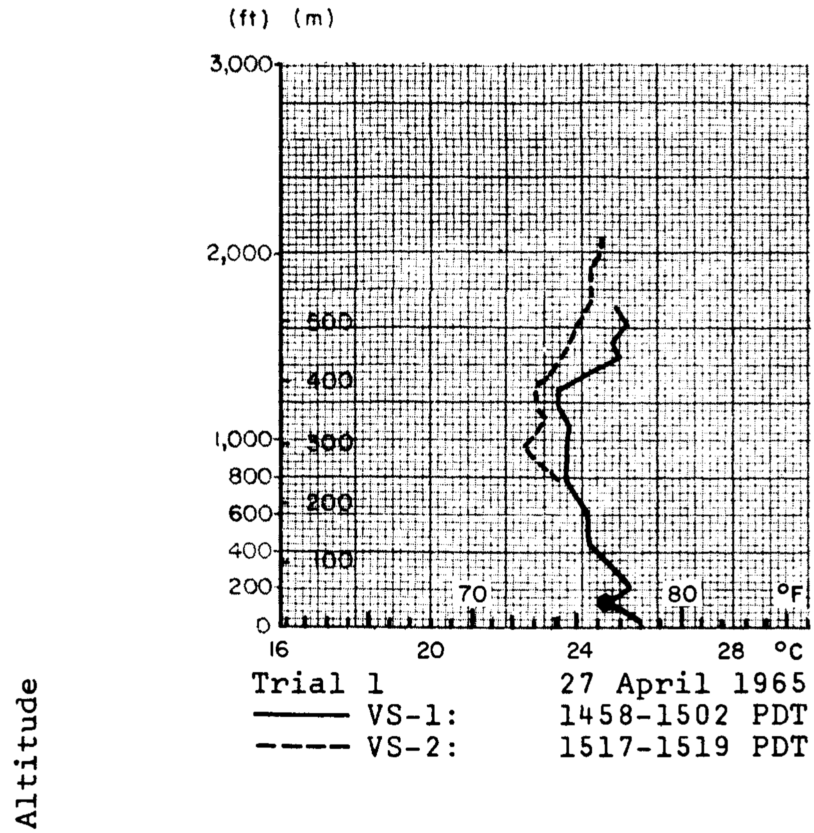
Trial: 31
Date: 12 October 1965
FP Release (Y): 1437:00
(G): 1419:00-1419:15

Site: S-2 Gantry (MRI)

Time	wd	ws
1410-1415	W	5.9
1415-1420	W	6.8
1420-1425	W	6.8
1425-1430	WSW	5.9
1430-1435	SW	6.8
1435-1440	SW	5.9
1440-1445	SSW	5.9
1445-1450	SW	5.1
1450-1455	WSW	5.9
1455-1500	WSW	5.1
1500-1505	WSW	4.2
1505-1510	WSW	5.1

AIRCRAFT TEMPERATURE SOUNDINGS

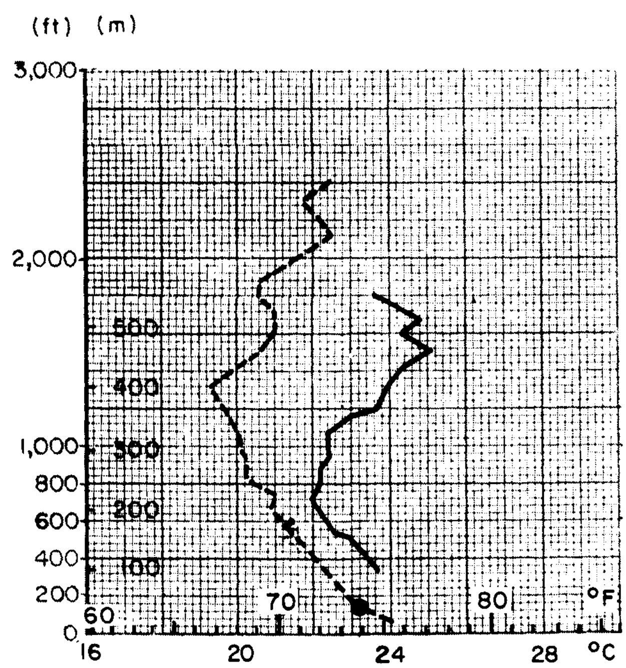
Project Sycamore Canyon



Trial 1 27 April 1965

——— VS-1: 1458-1502 PDT

- - - - VS-2: 1517-1519 PDT



Trial 1 27 April 1965

——— VS-3: 1554-1557 PDT

- - - - VS-4: 1626-1628 PDT

● Temperature at 138 ft at S-2 Gantry

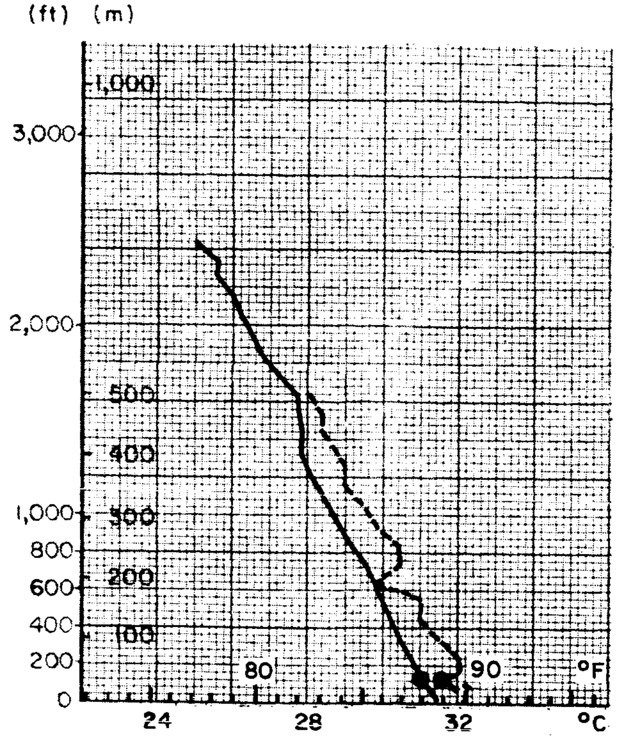
All altitudes are above ignition pad

AIRCRAFT TEMPERATURE SOUNDINGS

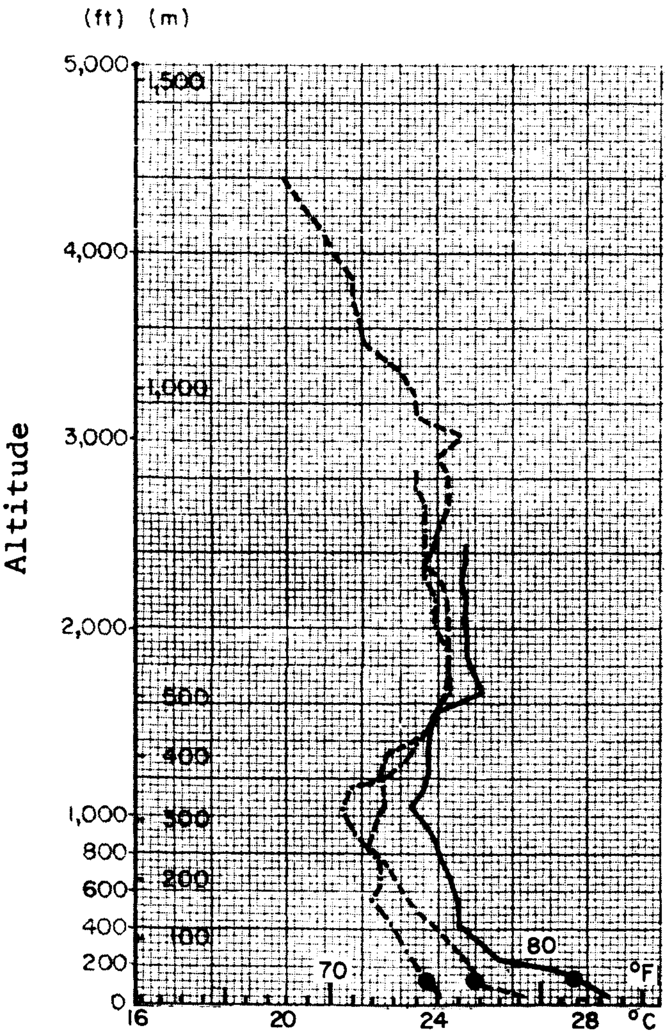
Project Sycamore Canyon

● Temperature at 138 ft at S-2 Gantry

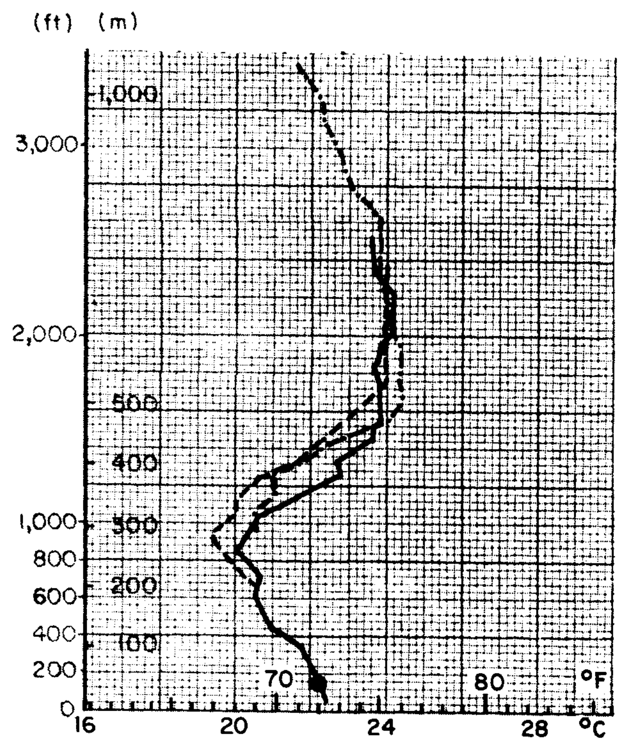
All altitudes are above ignition pad



Trial 4 28 April 1965
VS-1: 1346-1350 PDT
VS-2: 1421-1425 PDT



Trial 5 28 April 1965
VS-1: 1550-1553 PDT
VS-2: 1608-1616 PDT
VS-3: 1634-1638 PDT



Trial 5 28 April 1965
VS-4: 1723-1728 PDT
VS-5: 1742-1745 PDT
VS-6: 1757-1801 PDT

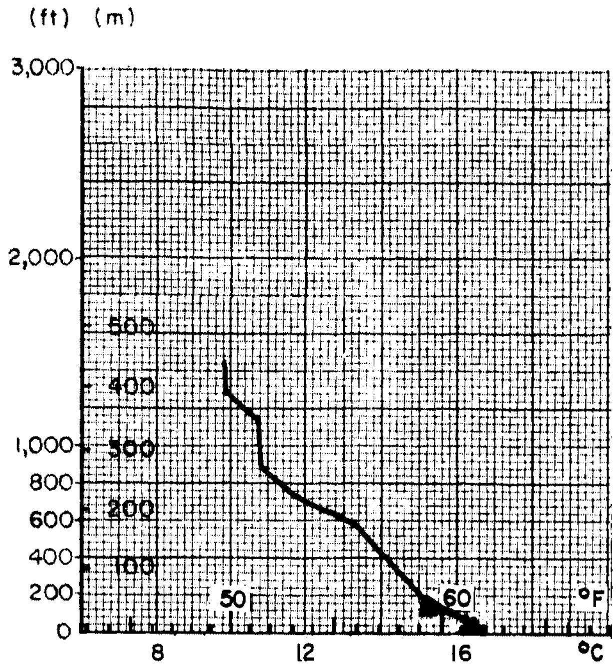
AIRCRAFT TEMPERATURE SOUNDINGS

Project Sycamore Canyon

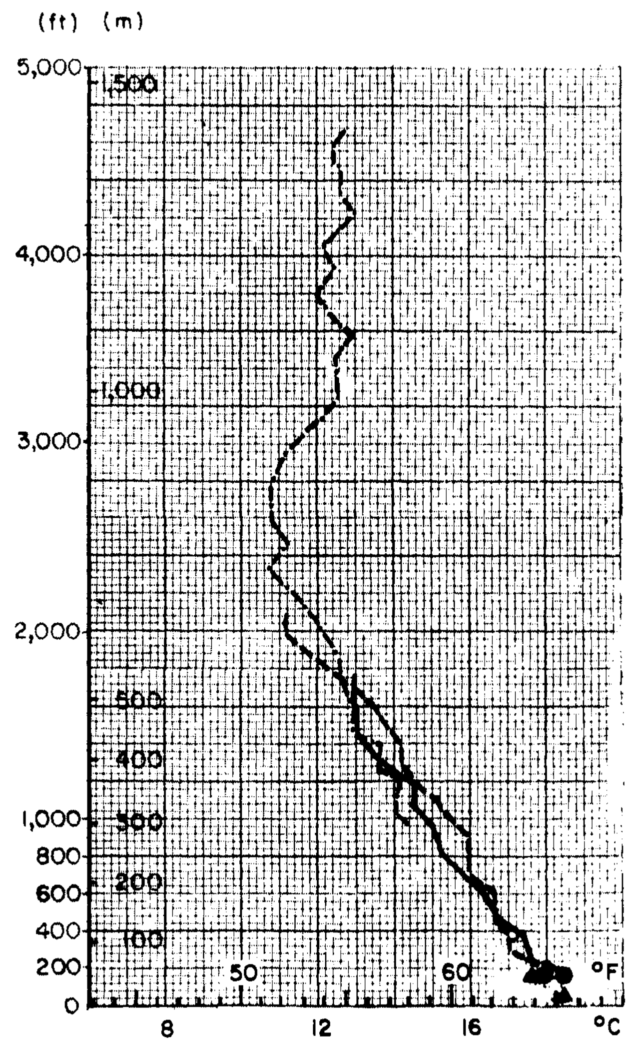
- ● Temperature at 138 ft at S-2 Gantry
- ▲ Temperature at S-2 Gantry at release time

All altitudes are above ignition pad

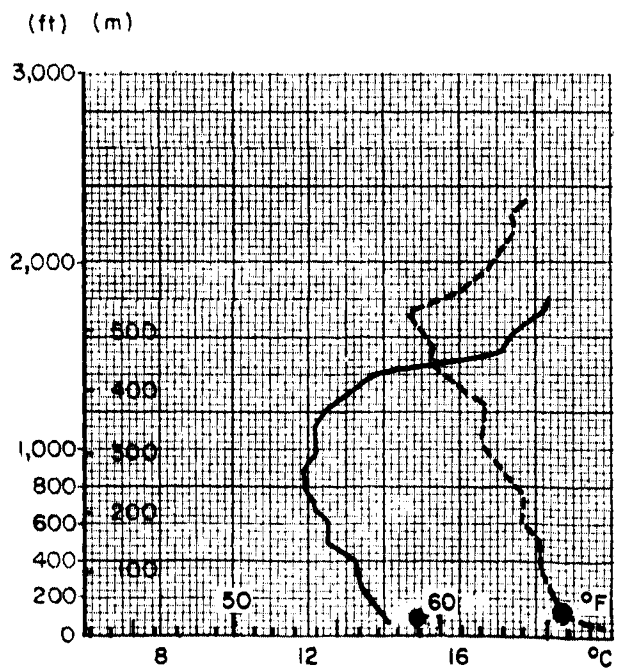
Altitude



Trial 8 8 June 1965
——— VS-1: 1456-1458 PDT



Trial 11 14 June 1965
——— VS-1: 1400-1403 PDT
- - - - VS-2: 1515-1520 PDT
—·—·— VS-3: 1443-1449 PDT

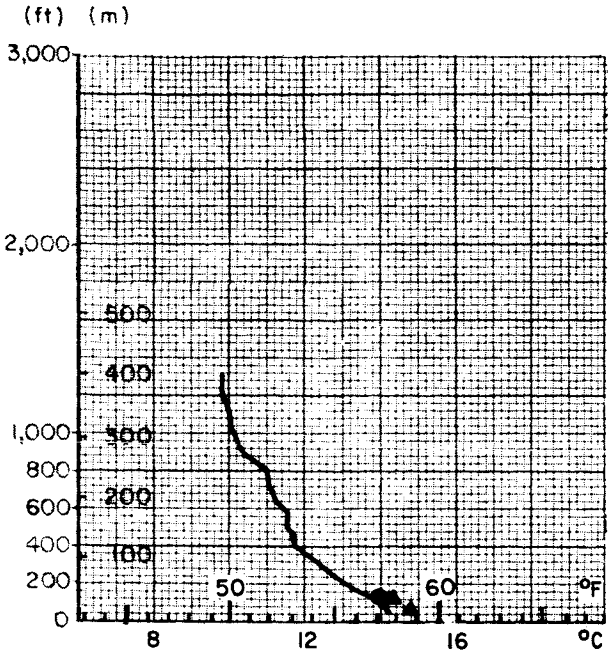


Trial 10 11 June 1965
——— VS-1: 0856-0859 PDT
- - - - VS-2: 1009-1011 PDT

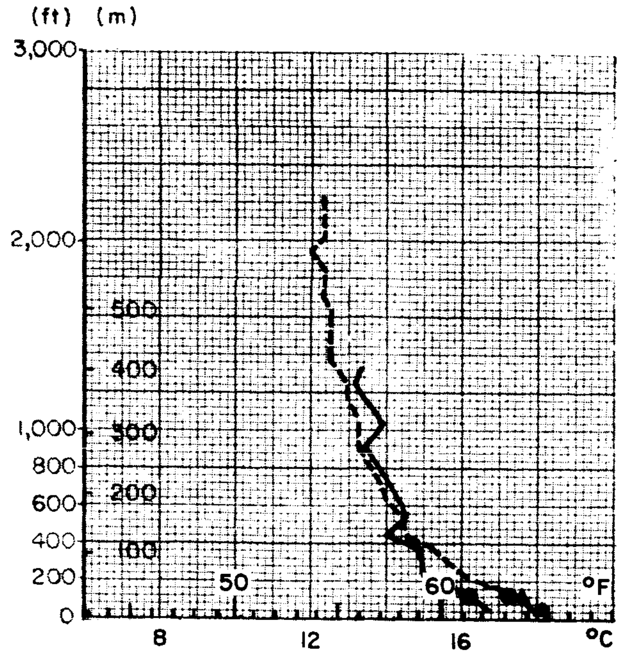
AIRCRAFT TEMPERATURE SOUNDINGS

Project Sycamore Canyon

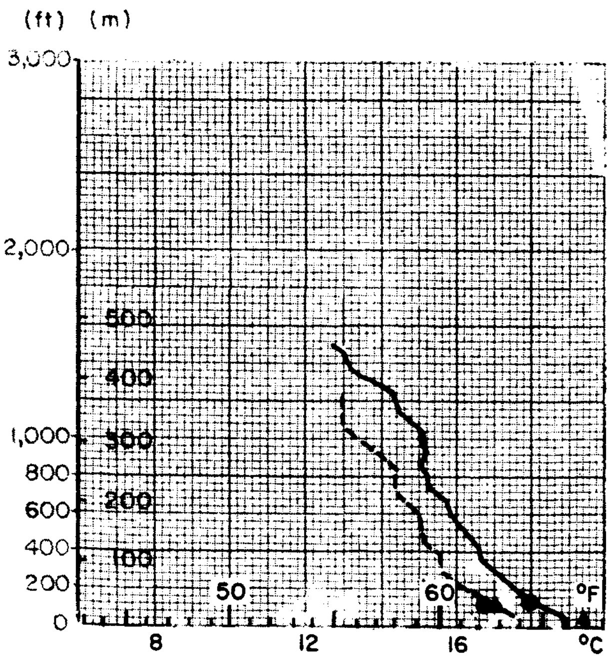
Altitude



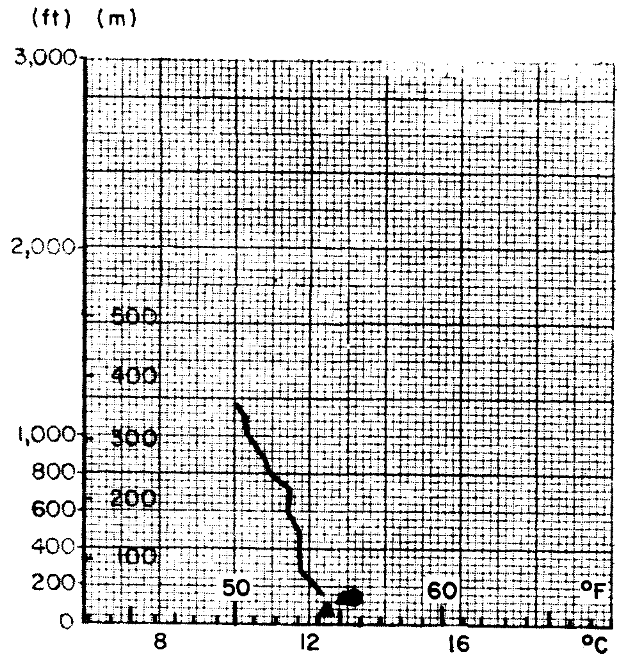
Trial 12 — VS-1: 17 June 1965, 0934-0936 PDT



Trial 13 — 24 June 1965
VS-1: 1041-1044 PDT
VS-2: 1258-1300 PDT



Trial 14 — 24 June 1965
VS-3: 1547-1549 PDT
VS-4: 1715-1717 PDT



Trial 15 — VS-1: 25 June 1965, 1342-1344 PDT

● Temperature at 138 ft at S-2 Gantry

▲ Temperature at S-2 Gantry at ignition time

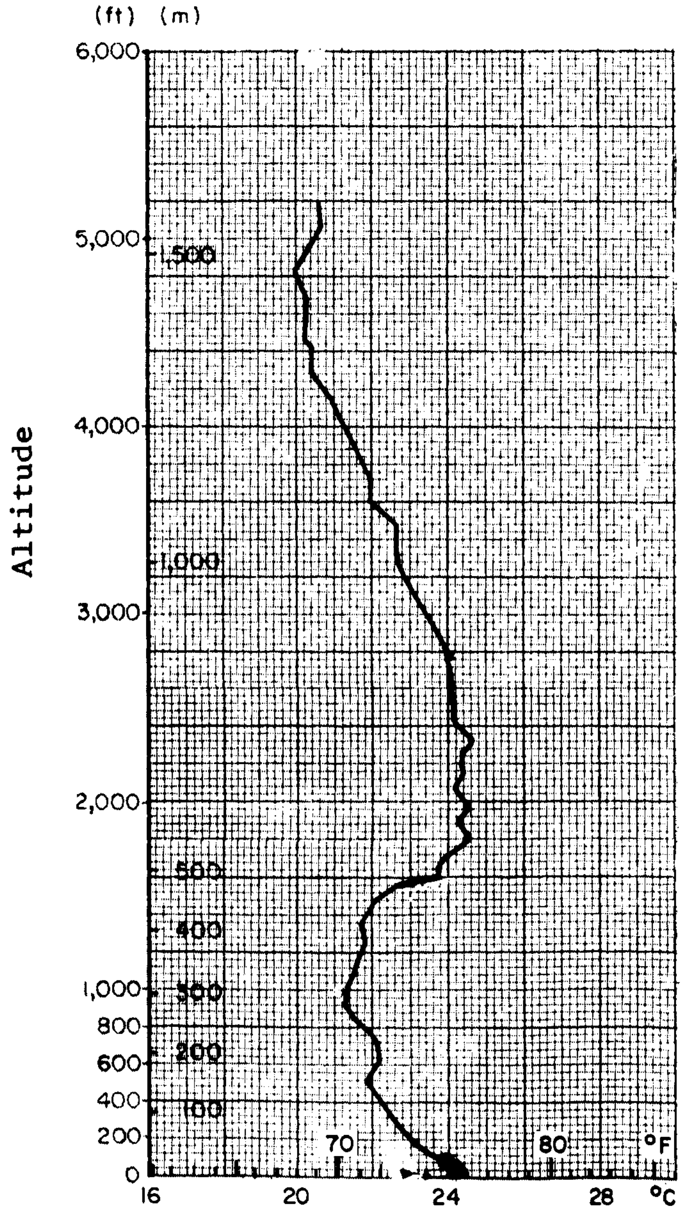
All altitudes are above ignition pad

Project Sycamore Canyon

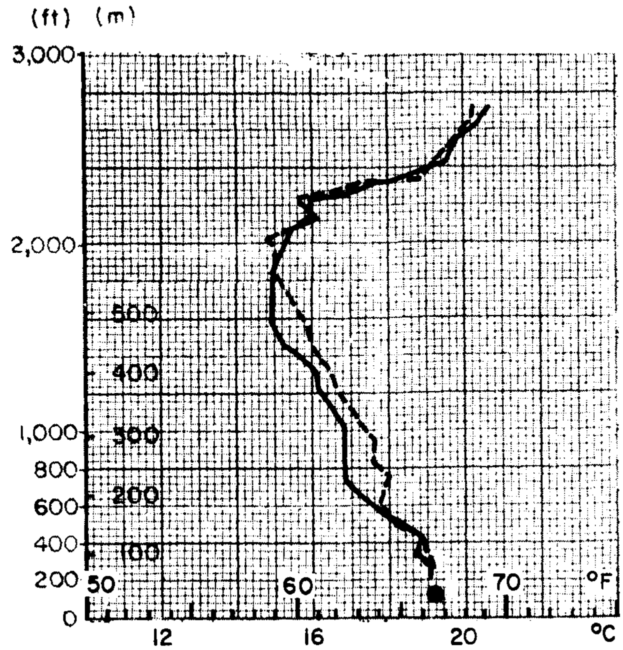
Temperature at 138 ft
at S-2 Gantry

▲ Temperature at S-2 Gantry
at ignition time

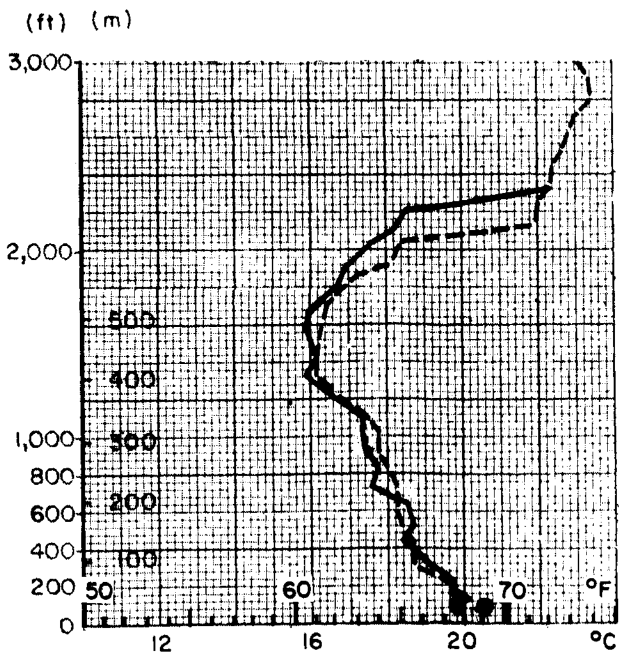
All altitudes are above
ignition pad



Trial 19 8 July 1965
——— VS-1: 1254-1300 PDT



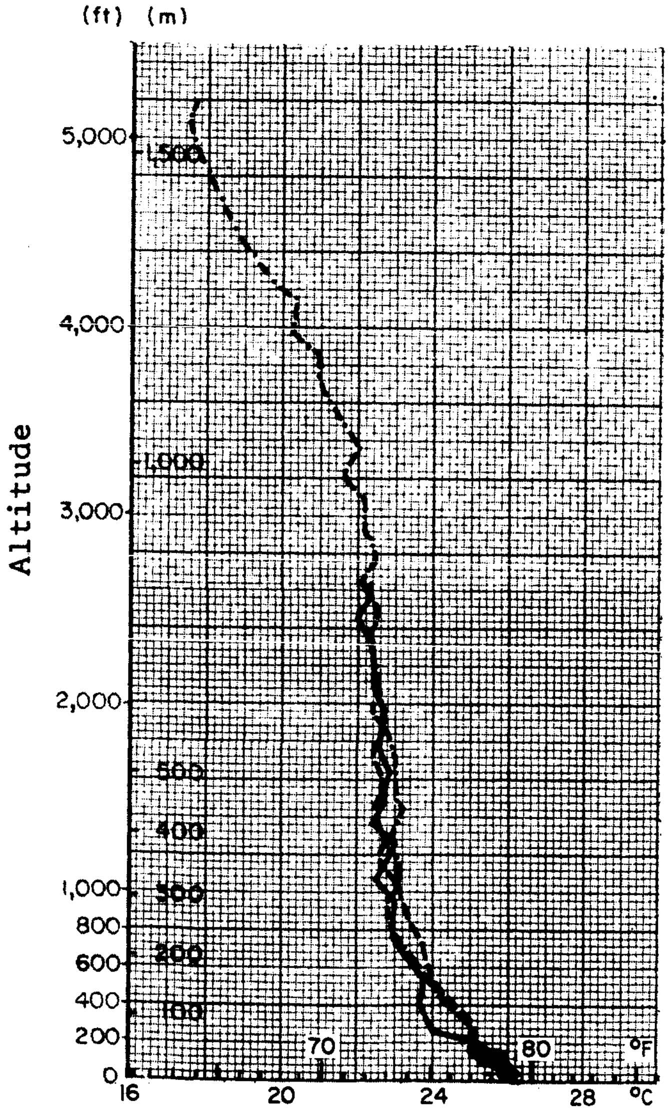
Trial 20 8 July 1965
——— VS-1: 1122-1128 PDT
---- VS-2: 1129-1135 PDT



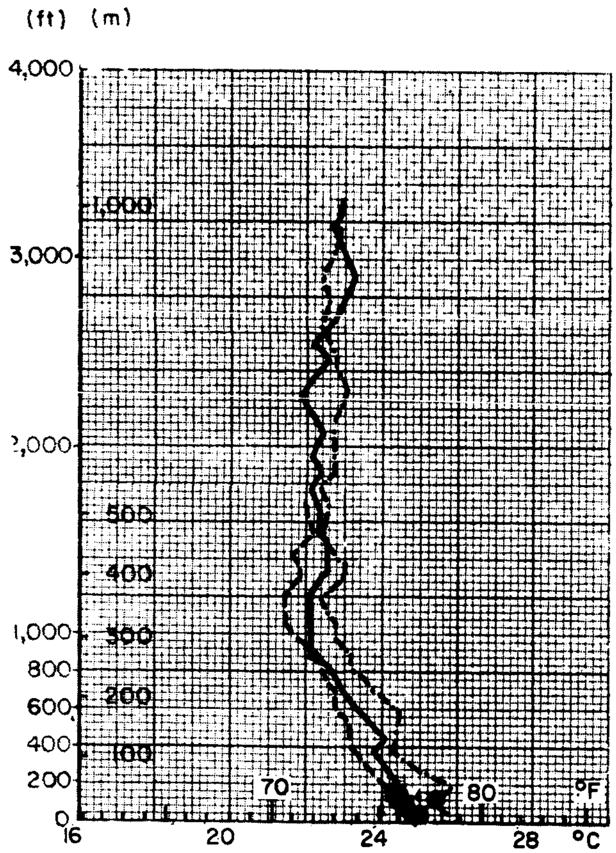
Trial 20 12 July 1965
——— VS-3 1421-1426 PDT
---- VS-4 1547-1554 PDT

AIRCRAFT TEMPERATURE SOUNDINGS

Project Sycamore Canyon



Trial 21 19 July 1965
——— VS-1: 1304-1309 PDT
---- VS-2: 1323-1329 PDT
—·—·— VS-3: 1522-1533 PDT



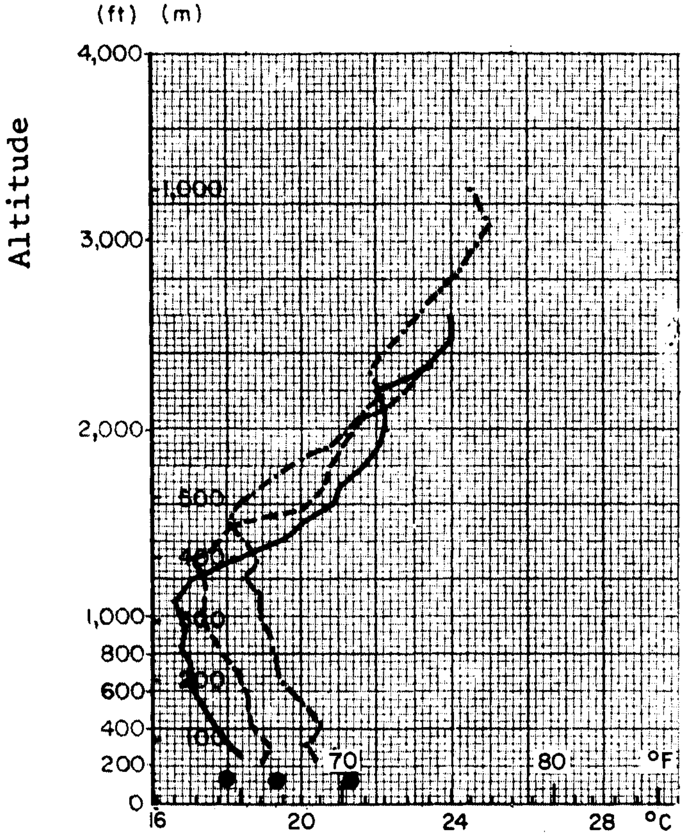
Trial 22 21 July 1965
——— VS-1: 1213-1220 PDT
---- VS-2: 1232-1235 PDT
—·—·— VS-3: 1315-1321 PDT

● Temperature at 138 ft at S-2 Gantry

▲ Temperature at S-2 Gantry at release time

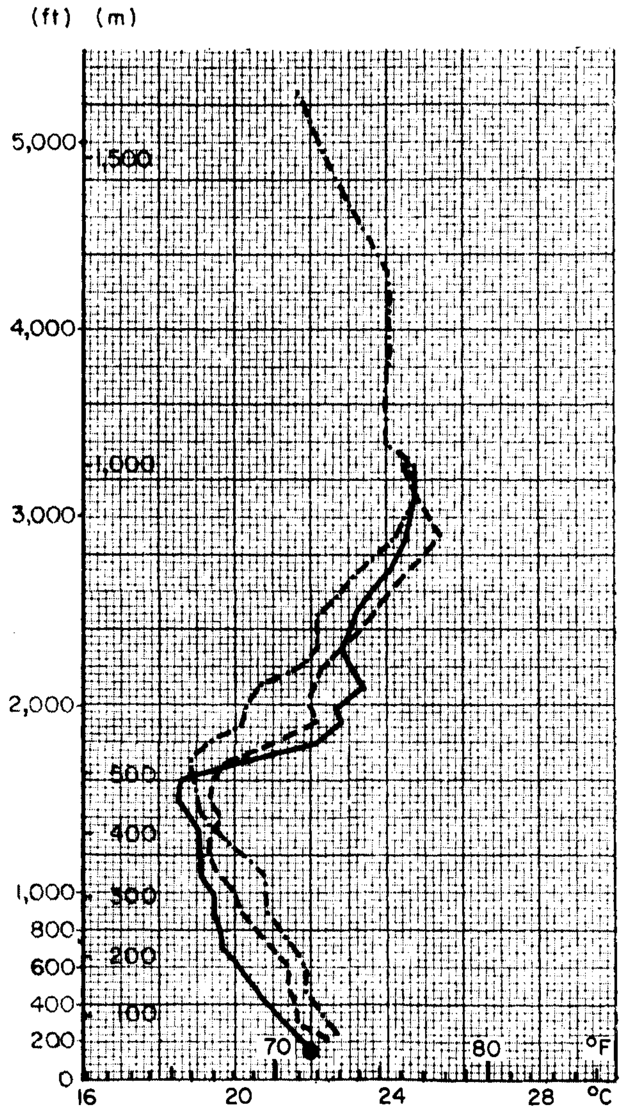
All altitudes are above ignition pad

AIRCRAFT TEMPERATURE SOUNDINGS
Project Sycamore Canyon



Trial 23 27 July 1965

———	VS-1:	0853-0858 PDT
----	VS-2:	0930-0934 PDT
—·—·—	VS-3:	0956-1003 PDT



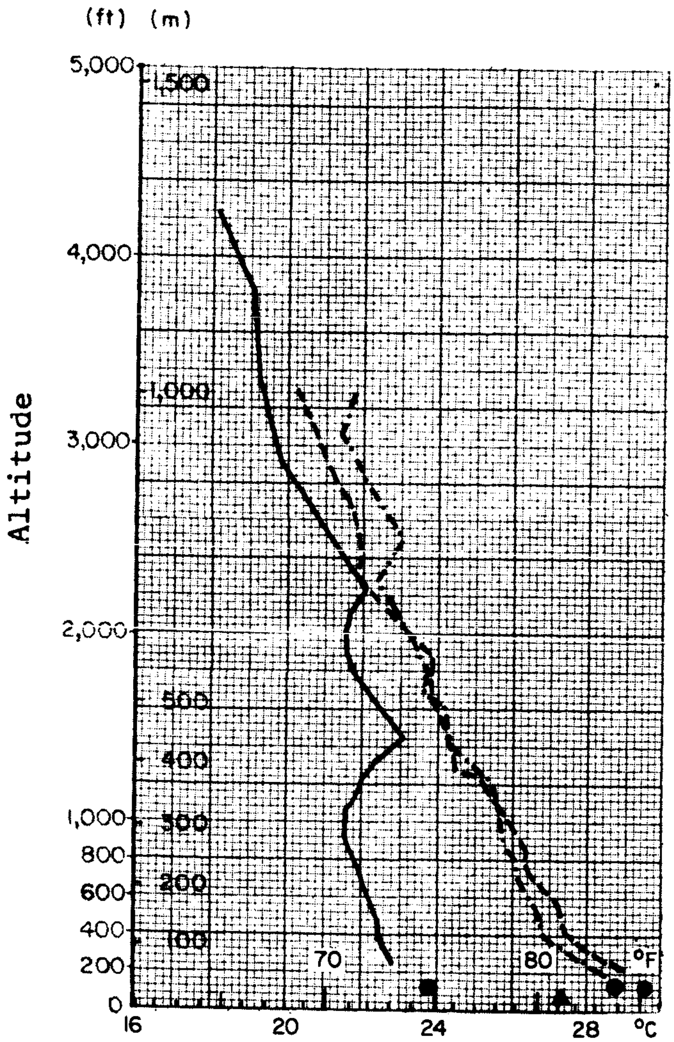
Trial 23 .27 July 1965

———	VS-4:	1029-1034 PDT
----	VS-5:	1041-1048 PDT
—·—·—	VS-6:	1052-1104 PDT

● Temperature at 138 ft at S-2 Gantry
All altitudes are above ignition pad

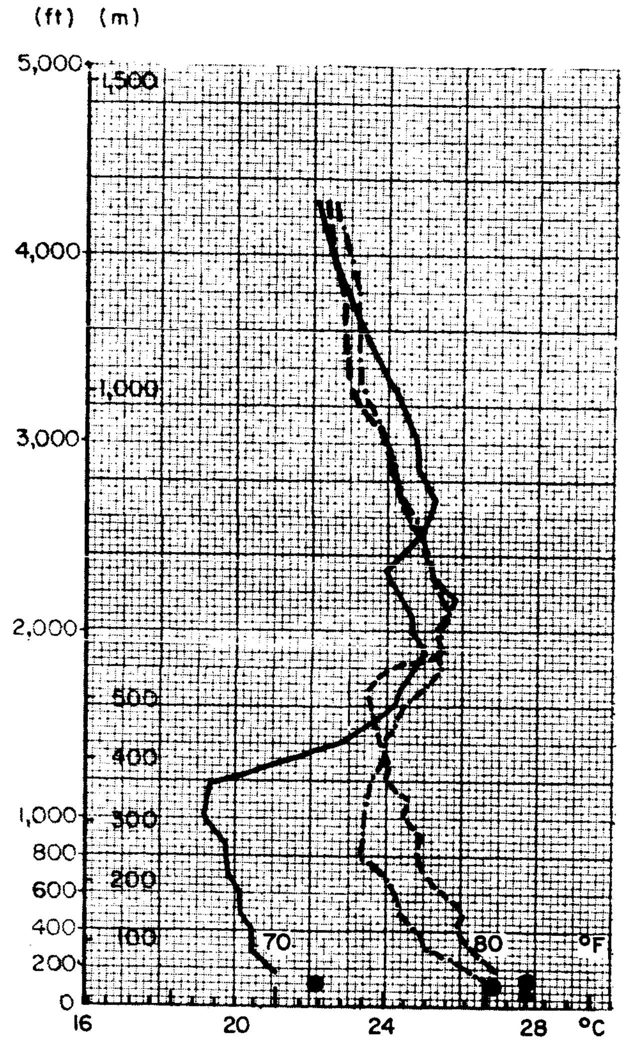
AIRCRAFT TEMPERATURE SOUNDINGS

Project Sycamore Canyon



Trial 24 — 30 July 1965

———	VS-1:	0906-0914 PDT
- - - -	VS-2:	1301-1307 PDT
—·—·—	VS-3:	1359-1405 PDT



Trial 25 — 4 August 1965

———	VS-1:	1002-1012 PDT
- - - -	VS-2:	1232-1240 PDT
—·—·—	VS-3:	1325-1334 PDT

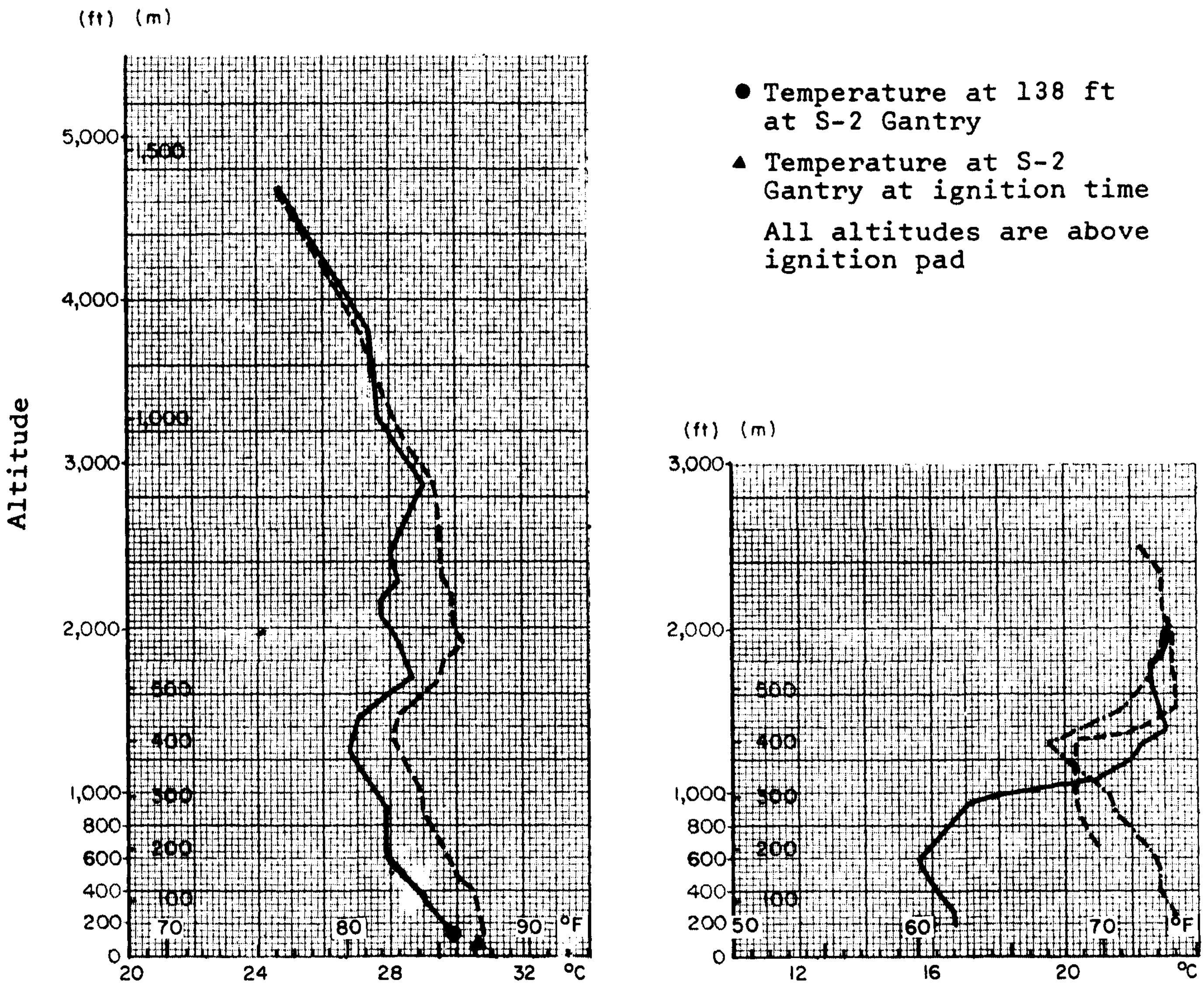
● Temperature at 138 ft at S-2 Gantry

▲ Temperature at S-2 Gantry at ignition time

All altitudes are above ignition pad

AIRCRAFT TEMPERATURE SOUNDINGS

Project Sycamore Canyon



● Temperature at 138 ft at S-2 Gantry

▲ Temperature at S-2 Gantry at ignition time

All altitudes are above ignition pad

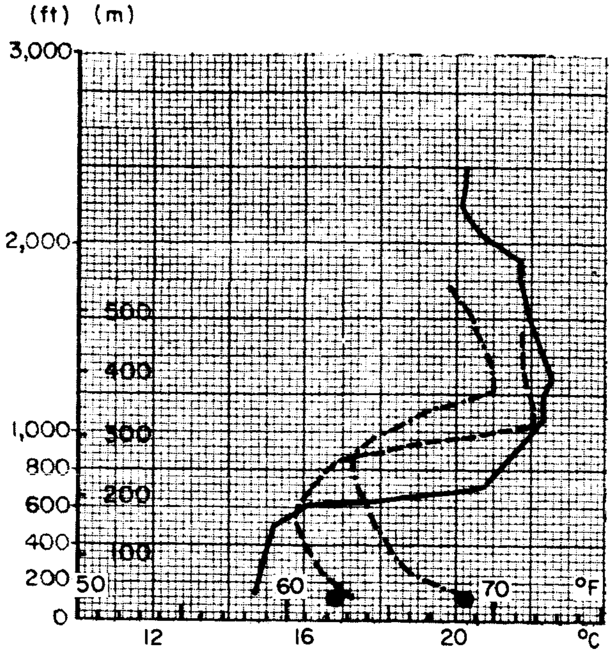
Trial 26	9 August 1965
——— VS-1:	0931-0940 PDT
---- VS-2:	1102-1110 PDT

Trial 27	31 August 1965
——— VS-1:	0836-0839 PDT
---- VS-2:	1025-1028 PDT
—·—·— VS-3:	1037-1043 PDT

AIRCRAFT TEMPERATURE SOUNDINGS

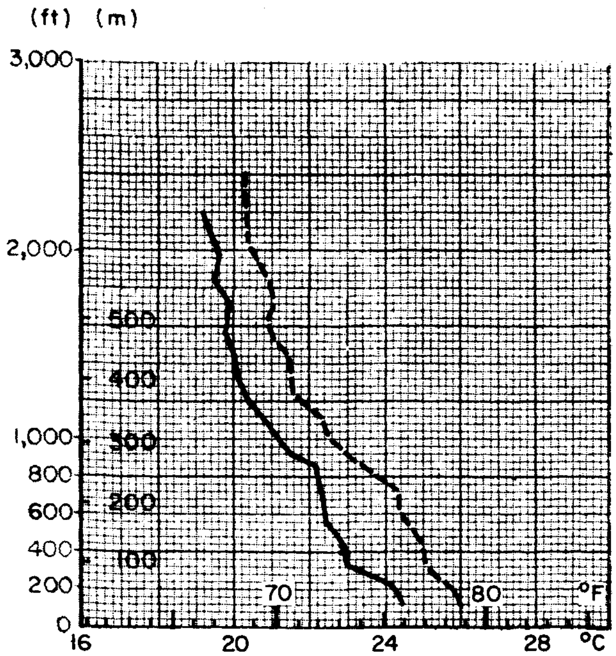
Project Sycamore Canyon

Altitude



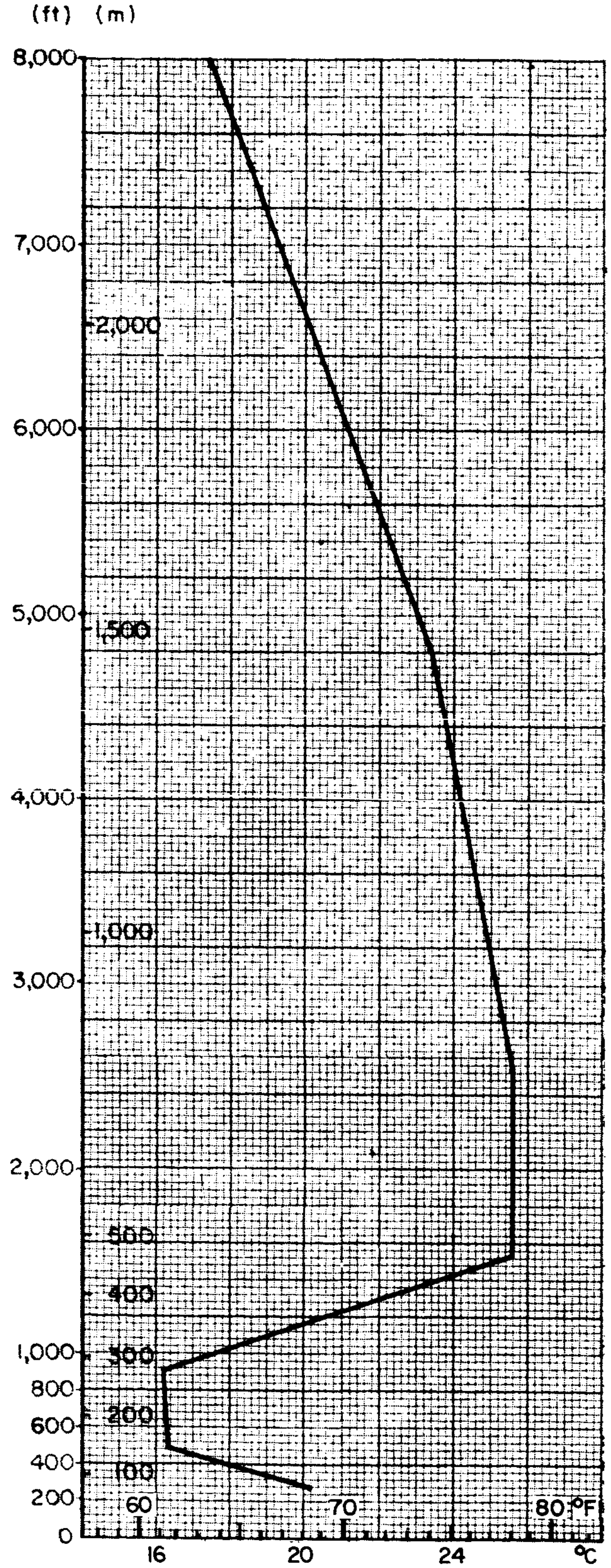
Trial 28 3 September 1965

- ——— VS-1: 0817-0820 PDT
- ---- VS-2: 0907-0909 PDT
- —·—·— VS-3: 1000-1002 PDT



Trial 28 and 29 3 September 1965

- ——— VS-4: 1141-1143 PDT
- ---- VS-5: 1349-1353 PDT



Trial 31 12 October 1965
Montgomery Field Rawinsonde
1700 PDT

● Temperature at 138 ft at S-2 Gantry

All altitudes are above ignition pad

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